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THESIS

VOIP QUALITY MEASUREMENTS IN A MULTILEVEL SECURE (MLS) ENVIRONMENT

by

Coy M. Adams, Jr.

March 2008

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Voice over Internet Protocol (VoIP) is growing in popularity in the civilian and military communities due to its low cost and the management advantages it offers over traditional Public Switched Telephone Networks (PSTN) phone systems. Many military commands do not have the infrastructure or funding that is required to support the rapid expansion of multiple phone services at various locations throughout the world. VoIP offers a rapidly deployable alternative. A subjective study was designed to test the quality of Voice over Internet Protocol (VoIP) signals in a controlled and isolated multilevel secure network to which single level networks were attached. The experiment provided useful insights regarding VoIP testing with human subjects and its procedures can be repeated as the Monterey Security Architecture (MYSEA) project moves forward with the implementation and deployment of VoIP services in its multilevel testbed.

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VOIP QUALITY MEASUREMENTS IN A MULTILEVEL SECURE (MLS) ENVIRONMENT

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ABSTRACT

Voice over Internet Protocol (VoIP) is growing in popularity in the civilian and military communities due to its low cost and the management advantages it offers over traditional Public Switched Telephone Networks (PSTN) phone systems. Many military commands do not have the infrastructure or funding that is required to support the rapid expansion of multiple phone services at various locations throughout the world. VoIP offers a rapidly deployable alternative. A subjective study was designed to test the quality of Voice over Internet Protocol (VoIP) signals in a controlled and isolated multilevel secure network to which single level networks were attached. The experiment provided useful insights regarding VoIP testing with human subjects and its procedures can be repeated as the Monterey Security Architecture (MYSEA) project moves forward with the implementation and deployment of VoIP services in its multilevel testbed.

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GLOSSARY

ARP: Address Resolution Protocol is a core protocol in the Transmission Control Protocol/Internet Protocol (TCP/IP), and is used to obtain the physical address of a host or node. [1]

CONFIDENCE INTERVAL: The confidence interval is an estimate of a population parameter that consists of a range of values bound by statistics referred to as "upper" and "lower" confidence limits, within which the value of the parameter is expected to be located.[2]

CONFIDENCE LEVEL: The confidence level is an expression that represents how often the true percentage of the population would choose an answer which lies within the confidence interval's upper and lower limits.[3]

ENCODING: The process of transforming information from one format into another format. [4]

GATEWAY: A router that connects two networks and can perform protocol conversion.[5]

IEC: International Electro-technical Commission is an international standards and conformity assessment body for all fields of electro-technology.

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1 Tamara Dean, Network + Guide to Networks, Thomson Course Technology, 2006.

2 Creative Research Systems, The Survey System (URL); http://www/surveysystem.com/sscalc.htm, [Accessed: February 20, 2008].

3 Ibid.

4 Charlie Kaufman, Radia Perlman, Mike Speciner, Network Security Private Communication in a Public World, Prentice Hall PTR, 1995.

5 Mani Subramanian,, Network Management, Principles and Practice, Addison-Wesley, 2000.

IPv4: Internet Protocol version 4 is the fourth iteration of the Internet Protocol and is the Current standard for IP addressing. It specifies 32-bit addresses composed of four octets.[6]

IPv6: Internet Protocol version 6 (IPv6) is a newer standard Internet Protocol addressing that will replace the IPv4. IPv6 uses a newer, more efficient header in its packets and allows for 128-bit source and destination IP addresses. The addition of longer addresses will allow for more addresses.[7]

ISO: International Organization of Standardization is an international standard-setting body composed of representatives from various national standards organizations.[8]

ITU: International Telecommunications Union is a United Nations agency that regulates international telecommunications and provides developing countries with technical expertise and equipment to advance their technological bases.[9]

ITU-T: International Telecommunication Union Telecommunications Standardization Sector is a permanent subdivision of the International Telecommunications Union (ITU) and is responsible for providing standards by studying, and operating telecommunication networks.[10]

MAC: Media Access Control address is a 12 character string that uniquely identifies a network node.[11]

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6 Tamara Dean, Network + Guide to Networks, Thomson Course Technology, 2006.

7 Ibid.

8 Charlie Kaufman, Radia Perlman, Mike Speciner, Network Security Private Communication in a Public World, Prentice Hall PTR, 1995.

9 Tamara Dean, Network + Guide to Networks, Thomson Course Technology, 2006.

10 International Telecommunications Union Standardization Sector (ITU-T), General Information, http://www.itu.int/ITU-T/info/index.html, [Accessed: February 14, 2008].

11 Tamara Dean, Network + Guide to Networks, Thomson Course Technology, 2006.

MLS: Multilevel Security: A class of systems containing information at different classification levels. Access decisions are based on the subject's security clearances, need to know and formal approval.[12]

MYSEA: The Monterey Security Architecture is a trusted, distributed environment enforcing multilevel security policies.

NIPRNet: Unclassified but Sensitive Internet Protocol Router Network, (formerly called the Non-Classified Internet Protocol Router Network). NIPRNet is used to exchange unclassified but sensitive information between "internal" users and also provides user access to the Internet.

PSTN: The Public Switched Telephone Network is the network of the world's public circuit-switched telephone networks.

QoS: Quality of Service is the ability to guarantee a certain level of performance for a data flow.[13]

SIP: Session Initiation Protocol is an application-layer control (signaling) protocol for creating, modifying, and terminating sessions with one or more participants. These sessions include Internet telephone calls (VoIP), multimedia distribution, and multimedia conferences.[14]

SIPRNet: The SIPRNet (Secret [formerly Secure] Internet Protocol Router Network) is a system of interconnected computer networks used by the U.S. Department of Defense and the U.S. Department of State to transmit classified information (up to and including

12 Shon Harris, CISSP All-in-One Guide Third Edition, McGraw-Hill, 2005.

13 Ibid.

14 J. Rosenbury, The Internet Engineering Task Force (IETF), Request For Comments (RFC) 3261, The Internet Society, 2002, http://www.ieft.org/rfc/rfc3261.txt, [Accessed: February 14, 2008].

information classified SECRET) in an identification and authentication environment that is isolated from the NIPRNet through a combination of logical and physical measures.

SSO: Single Sign-On (SSO) is a method of access control that enables a user to authenticate once and gain access to the resources of multiple software systems.[15]

TCP/IP: Transmission Control Protocol/Internet Protocol is a suite of networking protocols that provides the foundation for data exchange across the Internet.[16]

TPE: Trusted Path Extension is a device responsible for providing a secure interface for user interaction with selected MYSEA server security functions.[17]

VoIP: Voice over Internet Protocol is a protocol for providing telephone service over a packet-switched network running the TCP/IP protocol suite.[18]

WTSA: World Telecommunication Standardization Assembly defines general policy and adopts working methods and procedures for the ITU-T.

XML: The Extensible Markup Language (XML) is a general-purpose markup language. It is used on the World Wide Web in the context of the Hyper-Text Transfer Protocol. [19]

15 Shon Harris, CISSP All-in-One Guide Third Edition, McGraw-Hill, 2005, 149-151.

16 Tamara Dean, Network + Guide to Networks, Thomson Course Technology, 2006.

17 Thuy D. Nguyen, Timothy E. Levin, Cynthia E. Irvine, MYSEA Testbed, 2004.

18 Tamara Dean, Network + Guide to Networks, Thomson Course Technology, 2006.

19 E. Whitehead, The Internet Engineering Task Force (IETF), Request For Comments (RFC) 2376, The Internet Society, 1998, <http://www.ieft.org/rfc/rfc2376.txt>, [Accessed: February 14, 2008].

ACRONYMS AND ABBREVIATIONS

ARP	Address Resolution Protocol
CAT 5	Category 5 network cabling
COTS	Commercial Off-The-Shelf
CPU	Central Processing Unit
DAV	Distributed Authoring and Versioning
DoD	Department of Defense
IEC	International Electro-technical Commission
IETF	Internet Engineering Task Force
IP	Internet Protocol
IPsec	Internet Protocol Security
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
ISO	International Organization of Standardization
ITU-T	International Telecommunications Union – Telecommunications Standardization Sector
LAN	Local Area Network
MAC	Media Access Control
MLS	Multilevel Security
MOS	Mean Opinion Score
MYSEA	Monterey Security Architecture
NIPRNet	Non-Classified Internet Protocol Router Network
NPS	Naval Postgraduate School
PC	Personal Computer
PSTN	Public Switched Telephone Network
QoS	Quality of Service
SIP	Session Initiation Protocol
SIPRNet	Secure Internet Protocol Router Network
SSO	Single Sign-On

TCP/IP	Transmission Control Protocol/Internet Protocol
TPE	Trusted Path Extension
VoIP	Voice over Internet Protocol
WAN	Wide Area Network
WLAN	Wireless Local Area Network
WTSA	World Telecommunication Standardization Assembly
XML	Extensible Markup Language

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I. INTRODUCTION

Voice over Internet Protocol (VoIP) is a growing technology that has been adopted and used by various components of the commercial sector. As with most of today's advanced technology, the military is adopting this new digital communication concept, with some of the military services planning to implement VoIP in ground and sea deployments to provide integrated communications at all levels of the command structure[20].

The primary focus of utilizing VoIP technology is to provide voice communication down to the lowest level within the command. This technology will permit data exchange between separate commands without the need to deploy legacy Public Switched Telephone Networks (PSTN) equipment or infrastructures regardless of the location. When a command is deployed and interconnected to the main information grid, members of the command are able to communicate with one another, as well as with senior authorities as needed. [21]

As the term Voice over IP implies, it is a PSTN replacement that enables connectivity to go beyond just speech communication. VoIP can be used for automatically sending additional information in the form of chat, video streaming, application files, and other web-based application sharing features.

Even though the immediate deployment of VoIP in battle conditions is more spectacular and draws attention, VoIP's beneficial contribution to permanent installations such as naval bases or naval air stations must not be downplayed. It is easy to see why VoIP should be considered for wide deployment, especially considering the cost savings

20 Maryann Lawlor, Jeff Hawk, Henry S. Kenyon, Panelists Explore Network Centricity's Many Facets, SIGNAL AFCEAS; International Journal, August 2005, http://www.afcea.org/signal/articles/templates/SIGNAL_Article_Temlate.asp?articleid=10118&zoneid=8, [Accessed: March 21, 2007].

21 CMDR Jeffrey W. Eggers, Networks and Knowing, Armed Forces Journal, February 2008.

compared to traditional public switched telephone networks (PSTN). The installation cost is also decreased since the existing network infrastructure is used and manpower skills needed for administration are reduced[22]

The real evolution in military communications will come from the combined use of VoIP within multilevel secure and non-multilevel secure networks. A deployed command will not need to carry copper/fiber cable, to enable communications. All commands can be interconnected without physical cabling linking them, and all service personnel can communicate seamlessly. First, the man-hours and skills needed to deploy and effectively administer the network are minimal, which is an important factor when the available manpower is limited and time is crucial. Second, it allows for further network expansion when additional troops arrive and the need for communication between networks is urgent[23].

A. THESIS OBJECTIVE

This thesis explores the quality of Voice over Internet Protocol (VoIP), when configured within a multilevel secure network. Subjective testing has been used to compare the results obtained in four network configurations, two multilevel secure and two non-multilevel secure networks.

The International Telecommunications Standardization Sector (ITU-T) P.862.3,[24] was used as the standard in the subjective testing of voice quality within VoIP signals in a controlled and isolated multilevel network to which networks.

The Monterey Secure Architecture, MYSEA, was the test bed for the two multilevel secure networks. The two non-multilevel secure networks had similar configurations and all networks had VoIP software, Skype, installed.

Human test subjects were solicited from the staff and students of the Naval Postgraduate School to participate in the experiments. Each test subject was briefed and

22 Karen E. Thuermer, Gearing up for Networx, Military Information Technology, Vol 11, Issue 8, September 25, 2007.

23 B. Sklar, Digital Communications: Fundamental and Applications, Prentice Hall, Upper Saddle River, 2001.

24 ITU-T Recommendation P.862 (2001) – Amendment 2.

instructed to listen to sound files on each network configuration and complete a separate ten-item questionnaire regarding each sound file. Each questionnaire was graded and tabulated using a Mean Opinion Score (MOS), which were used for single and multi attribute analysis.

The hypothesis examined in this thesis is, “The quality of voice transmission over Internet Protocol networks in a multilevel secure network is comparable to a non-multilevel secure network.”

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II. BACKGROUND

A. OVERVIEW

This chapter presents background information pertaining to this thesis study. The focus is the qualitative assessment of Voice over Internet Protocol (VoIP) within the multilevel secure network of the MYSEA (Monterey Security Architecture). The assessment method used is based on the testing guidelines and standardization of the International Telecommunications Union Standardization Sector (ITU-T).

Although VoIP is an alternative to public switched telephone network (PSTN) services with respect to cost and flexibility, the quality of its output can determine whether, and under what conditions, VoIP will be acceptable to its end users when operated within a multilevel secure environment. This thesis will answer the following question: What is the quality of voice transmission over IP networks in a multilevel secure environment when compared to the same service in a non-multilevel secure environment?

B. INTERNATIONAL TELECOMMUNICATIONS UNION

The United Nations refers to the International Telecommunication Union (ITU) for specialized information and standards in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent subdivision of ITU. It is the ITU-T division's responsibility to study technical configurations, operating procedures and resolve questions along with issuing recommendations on each proposed issue and to provide a technical viewpoint on standardizing telecommunications on a worldwide basis. Another related organization, The World Telecommunication Standardization Assembly (WTSA), meets every four years, and establishes all of the topics for study by the ITU-T study groups. The ITU-T will then, produce recommendations on each of these topics. In some areas of information technology which fall within ITU-T's area of responsibility, standards are prepared by a collaborative foundation including the International Organization of Standardization (ISO) and The International Electro-technical Commission (IEC).

The International Telecommunications Union Standardization Sector (ITU-T) is the source of the standards for all test configurations and implementations used for this thesis study. The ITU's standards date back to 1865, the date of formation of the International Telegraph Union. The ITU-T has been an intergovernmental public-private partnership organization since its inception. It became a specialized agency under the United Nations in 1947. It has a membership of 191 countries and over 700 public and private sector companies, as well as international and regional telecommunication entities.[25] It was renamed in 1993 to its current title: International Telecommunications Union Standardization Sector (ITU-T). Its mission is to ensure efficient and timely creation of standards covering all fields of telecommunications on a worldwide basis, as well as defining bookkeeping principles for international telecommunications services. ITU-T's use increased in the personal computer industry in the early 1980's, often endorsing "*de facto standards"* as the technology was under development. The ITU-T developed a streamlined process that minimized the time between initial proposals and the final approval. Sometimes the time frame is as short as three months. The ITU-T technical work is managed by multiple study groups. Those involved in the study groups are experts in telecommunications from all over the world.

C. MYSEA

The Monterey Security Enhanced Architecture (MYSEA) was created at the Naval Postgraduate School to provide a trusted distributed operating environment that enforces multi-domain security policies, and supports commercial off the shelf (COTS) applications. MYSEA provides an isolated networking environment for the enforcement of stringent mandatory security policies. The architecture consists of a network that operates with high assurance MYSEA servers, low assurance MYSEA clients, legacy single level networks, and dynamic security services. MYSEA supports a secure trusted path for communications between the user and the trusted operating system.

The trusted path of the MYSEA system is enabled by a Trusted Path Extension (TPE) device which creates a protected channel between itself and the MYSEA server.

25 International Telecommunication Union. (2005). Telecommunication indicators Handbook. Geneva: ITU. <http://www.itu.int/ITU-D/ict/material/handbook.pdf>, [Accessed: January 16, 2007].

The assurance properties of the TPE device ensure that the trusted path cannot be undermined by malware on any of the client workstations. Architecturally, the Trusted Path Extension provides the client's only access to the MYSEA network for each logged on user and at the user's sensitivity level.

The MYSEA test bed continues to evolve as a growing technology that includes:

a. Assured authentication and trusted paths to MLS services, (e.g., Email, Web-based Distributed Authoring and Versioning (DAV), etc.).
b. Application of high assurance system-security technology to the integration of commercial and legacy components.
c. Centralized security management.
d. Integration of high assurance MLS with existing sensitive networks (e.g., SIPRNET, etc.).
e. High assurance trusted communication channel techniques for managing access to various classified networks.
f. Use of open architectures and standards.
g. Experimentation on the use of an extensible markup language (XML) tags as security markings.
h. Design of secure single sign-on (SSO) across multiple MLS servers.
i. High assurance module authentication and verification.
j. Secure collaborative information sharing.

In order to maintain a strict and stable life cycle process within the MYSEA test bed, only authorized personnel are granted access to the multilevel networks and only secure hardware components and software releases are installed.[26]

D. VOIP

Voice over Internet Protocol (VoIP) was first introduced in 1995 by Vocal Tec Inc., a telecommunication company that had launched a multimedia PC-based product which allowed users to speak through a PC microphone and listen to the conversation

26 T. D. Nguyen, T. E. Levin , and C. E. Irvine, "MYSEA Test bed", Proceedings from the 6th IEEE Systems, Man and Cybernetics Information Assurance Workshop, West Point, NY, June 2005, 438-439.

from the PC's speakers. This product was referred as the Internet Phone. VoIP uses Internet Protocols as the data transmission vehicle. A VoIP system digitizes voice using an audio codec, divides the digitized voice into packets, and sends the packets over an IP network to the intended destination. All packets are routed through the network so they will travel the same path. Unlike a public switched telephone network (PSTN) or legacy phone call, no dedicated circuit is ever created for a VoIP call. The exact process required to set up a VoIP call is dependent on the VoIP protocol. Two types of protocols are necessary to complete a VoIP call:

1. *Signaling*, this has the function of establishing a session between the callers.
2. *Media transport,* which specifies the rules and formats of the actual voice packets.

For PSTN systems, a phone number is used to locate a phone via the switching network, whereas, a phone number in VoIP can be a regular PSTN phone number, an IP address, or an alias destination assignment. The "phone number" ultimately is translated to a 32-bit or 128-bit IP address, which is dependent on whether IPv4 or IPv6 is used. Every VoIP signaling protocol must be capable of providing address resolution in order for each call to reach its destination. There are four general VoIP communication modes that are dependent upon this address resolution protocol (ARP):

1. Phone-to-Phone,
2. Phone-to-PC
3. PC-to-Phone
4. PC-to-PC

Voice transmission is carried by both PSTN and IP networks under the first three modes, (Phone-to-Phone, Phone-to-PC, and PC-to-Phone). A VoIP service provider that interconnects the PSTN and VoIP networks is needed for the first three modes when a call originates from a PSTN network and arrives at a VoIP network or vice versa. Voice travels exclusively across the IP network in the fourth mode (PC-to-PC).

The VoIP technology is made up of five distinct services:

1. Signaling
2. Encoding

3. Transport
4. Session Initiation Protocol
5. Gateway Control

A signaling VoIP protocol establishes and manages a connection between the endpoints when a call is made; this service requires the use of the VoIP signaling protocol. Session Initiation Protocol (SIP) is used as the media transport protocol and is used for setting up and breaking down voice calls. A primary objective in using SIP is to provide a connection and call setup protocol for IP-based communications that can support a superset of the call processing functions and features present in the public switched telephone network (PSTN). These features permit telephone-like operations such as: dialing a number, enabling a telephone to ring, providing ring tones or a busy signal. Implementation and terminology are different in the SIP world but to the end-user, the behavior is similar to that of PSTN.

SIP is a peer-to-peer protocol, where it requires only a simple core network with intelligence signals distributed throughout the network. Although many other VoIP signaling protocols exist, SIP is characterized as having its roots in the IP community rather than the telecom industry. When the conversation takes place, voice has to be encoded before it is transmitted over the IP network. The encoded voice packets will then be transported via the IP network to the destination. A gateway may be needed to convert voice into another format suitable for the receiving network.[27]

[27] Uyless D. Black, Voice over IP, 2nd Edition, Upper Saddle River, NJ, Prentice Hall, 2002, 330.

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III. EXPERIMENTAL DESIGN

This chapter describes the test methodology used to evaluate the quality of the audio content transmitted using VoIP in different network architectures. These architectures included a typical infrastructure and the MYSEA infrastructure.

Testing was conducted on a dedicated test bed in the basement of Glasgow East and was based on a subjective approach using human test subjects. Each test subject answered a ten item questionnaire after listening to a sound file. This process was repeated for each of four different network configurations. All test data were collected from each test subject and retained for analysis.

An initial experiment (Experiment I) revealed a potential bias in one of the four sound files. The initial testing was conducted with 61 test subjects presented with of four separate network configurations, where they listened to four separate sound files (sound files A, B, C, and D). However, each sound file remained at the same test station throughout the entire testing process. A review of the results indicated that Station Two displayed significantly higher scores than the remaining three stations. This indicated the need for an additional experiment to identify any potential sound file bias.

A second experiment (Experiment II) was administered. It consisted of one basic network configuration at each of two separate testing stations. Forty new test subjects were solicited to participate in this experiment. For four test groups, the same four sound files were played in different order, (e.g., Trial 1: ABCD; Trial 2: BCDA; Trial 3: CDAB; Trial 4: DABC). The results of the second experiment indicated that Sound File B, had higher scores than the other three sound files regardless of the order in which they were presented.

The results of Experiment II revealed that Station Two in Experiment I had a sound file of higher quality. Sound File B words were more understandable and had an overall better quality than the other three files. With this bias revealed, the results from Station Two were not used and Station One was the baseline for comparison of Stations Three and Four in Experiment I.

A. EXPERIMENT I

The objective of this experiment was to measure voice quality using standard sound files downloaded from the International Telecommunications Union Standardization Sector (ITU-T) website and transmitted over four separate test configurations using Skype software.[28] Two test configurations included the MYSEA infrastructure for the multilevel secure network and two test configurations did not include the MYSEA infrastructure. The main objective of the tests described in the following subsections was to determine if VoIP voice quality changes between MLS and non-MLS networks.

1. Subject Sampling

Speech quality was determined as the result of a subjective test, where a pre-determined number of test subjects listen to and judge the test material over separate networks via a ten-item questionnaire. All test subjects were random volunteers from the students and staff associated with the Naval Postgraduate School. The sample size of 61 test subjects were selected from a total population of 1500 staff and students.[29] For a confidence level of 95% this sample size corresponds to a 12% confidence interval.[30]

Subjects were solicited through on-campus announcements which were posted at various academic buildings throughout campus, email solicitations from academic advisors/professors and classmates. These methods were the basis of success in obtaining the required sample size for both experiments.

2. Test Question Selection

Testing methods were centered on the objective of defining the subjective performance assessment of the quality of speech of VoIP in four separate network configurations. The method was a "listening test", where messages were presented

28 ITU-T Recommendation P.862 (2001) – Amendment 2.

29 Fred N. Kerlinger, Foundations of Behavioral Research, 3rd Edition, (CBS College Publishing, 1986), 117-119.

30 Creative Research Systems, The Survey System (URL); http://www/surveysystem.com/sscalc.htm, [Accessed: February 20, 2008].

aurally to all test subjects. Each test subject was given a ten-item questionnaire to answer at the conclusion of each sound file played at its associated station. Each of the test subject's opinions were rated on a cardinality rating scale of 0 to 5, with 5 being of greater quality. Appendix A shows how the subjective opinions were mapped to cardinality scores. The cardinality point system was not known to the subject. These results were measures of the perceived quality in four categories of perception: Listening-quality effort, Articulation, Acceptance, and Overall Impression. The listening scores made it possible to compare the effectiveness of different speech files over each of the four separate network configurations. The questionnaires used throughout both experiments (I and II) were the same and are included in Appendix A.[31]

3. Sound File Selection

ITU-T Recommendation P.862.3 was used to provide a guide for estimating listening speech quality by using reference sound files. This recommendation provides the necessary information for obtaining a stable and reliable reference for the listener's perception of speech quality.

It was recommended that the speech material consist of simple, short and meaningful sentences. These sentences were chosen to be easy to understand and were constructed into sets of two short sentences with no obvious connection of meaning between the sentences in a set. Additionally, in accordance with P.830, it was recommended that a minimum of two female and two male sound files be used for testing.[32]

4. Controlling Station

The experiment controller played the sample files for all test subjects prior to testing at each station for sound and accent familiarity. Additionally, he initiated all

31 ITU-T Recommendation P.85, Telephone Transmission Quality Subjective Opinion Tests, June 1994.

32 ITU-T Recommendation P.862.3, Telephone Transmission Quality, Telephone Installations, Local Line Networks, November 2005.

telephone connections between the controlling station and each of the testing stations via Skype VoIP software. The experiment controller used the same equipment for Experiments, I and II.

a. Equipment: Dell Desktop CPU (Dimension 8200); four individual ITU pre-recorded voice sound files, (two male, two female) played via RealPlayer Enterprise Player, Build: 6.0.11.1526, Copyright (c) 2004; (1) 4 ft, 3.5 mm stereo audio cable (Male/Male).

b. Network: Dell Desktop CPU connected to the Skype server via the Naval Postgraduate School Internet (unclassified Internet).

c. Setup: A standard 3.5mm stereo audio cable (Male/Male) was connected to the speaker output jack (back of PC) and to the microphone input jack (back of PC) to create a loopback circuitry in order for the sound file to be transmitted to the Skype Server and back to the connected client for each of the four station configurations.

NOTE: This testing was targeted for single connectivity, therefore, no conference calling features were tested or evaluated. All calls were made to one specific station at a time and only one file was transmitted over that connection.

5. Station One

a. Equipment: Dell Inspiron Notebook CPU (5150); Plantronics PC Headset.

b. Network: Dell Desktop CPU (Dimension 8200) physically connected to the NPS Internet using CAT 5 cabling.

c. Setup: ITU pre-recorded wave file played and transmitted from the experiment controller's desktop to the test subject's headset using Skype software.

d. Configuration: As shown in Figure 1 there was no intermediate MYSEA Server (direct connection to the Internet and the Skype Server). In this configuration, Station One is connected directly to the Internet, via NPS Internet, using Skype software installed on the Dell Inspiron Notebook. Prior to testing, the experiment controller ensured that the laptop was logged on and connected to the Internet. The experiment controller opened and activated the

Skype account for “Non-MLS One” client. After logging onto the Skype Server, the experiment controller initiated the call from the Dell desktop via the Skype Server. After the call was initiated and received by the “Non-MLS One” client, connectivity was established. Each test subject listened to File “A” at Station One, by using a Plantronics PC Headset.

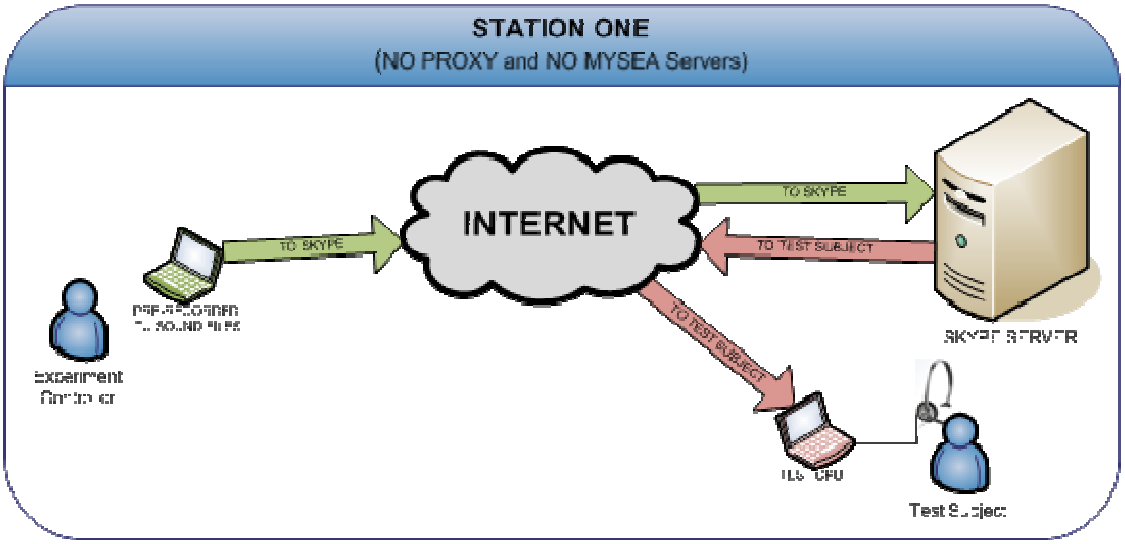

Figure 1. Station One

6. Station Two

a. Equipment: Dell Inspiron Notebook CPU (5150); Plantronics PC Headset.

b. Network: Dell Desktop CPU (Dimension 8200) physically to the NPS Internet with the Dell Inspiron Notebook CPU (5150) connected to a Proxy Server (Dell Desktop CPU-Dimension 8200) then into the NPS Internet using CAT 5 cabling.

c. Setup: ITU pre-recorded wave file played and transmitted from the experiment controller’s desktop to the test subject’s headset using Skype software.

d. Configuration: A proxy server is interposed between the test subject and the Internet, via NPS Internet. Figure 2 shows that Station Two is connected to the Internet using a proxy server, Dell Desktop CPU (Dimension 8200), and Skype software installed on the Dell Inspiron Notebook. Prior to testing, the

experiment controller ensured the proxy server, and laptop were energized and logged onto the Internet. The experiment controller opened and activated the Skype account for "Non-MLS Two" client. After logging onto to the Skype Server, the experiment controller initiated the call from the Dell desktop via the Skype Server. After the call was initiated and received by the "Non-MLS Two" client, connectivity was established. Each test subject listened to File "B" at Station Two, by using a Plantronics PC Headset.

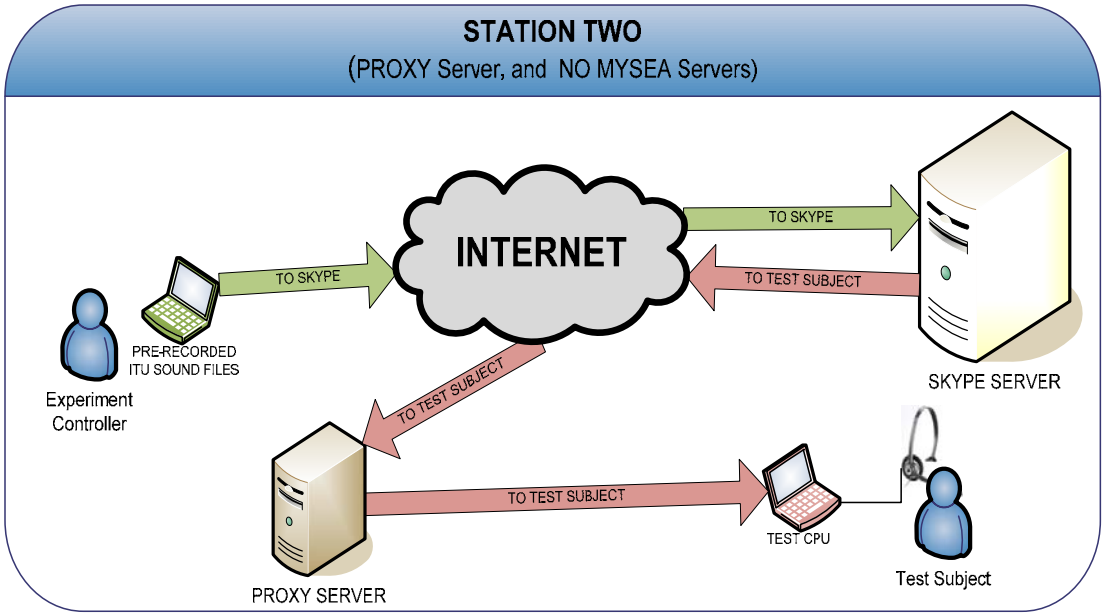

Figure 2. Station Two

7. Station Three

a. Equipment: Dell Inspiron Notebook CPU (5150); Plantronics PC Headset.

b. Network: Dell Desktop CPU (Dimension 8200) physically to the NPS Internet. The Dell Inspiron Notebook CPU (5150) is connected to a Trusted Path Extension (TPE) through a MYSEA Server (BAE XTS 400) then into the NPS Internet using CAT 5 cabling.

c. Setup: ITU pre-recorded wave file played and transmitted from the experiment controller's desktop to the test subject's headset using Skype software.

d. Configuration: MYSEA Server and Trusted Path Extension (TPE) are routed between Station Three and the Internet via NPS Internet. Figure 3 shows that Station Three is connected to the Internet via MYSEA using Skype software installed on the Dell Inspiron Notebook. Prior to testing, the experiment controller ensured the MYSEA server, and the laptop were energized and logged onto the Internet. The experiment controller opened and activated the Skype account for "MLS Three" client. After logging onto to the Skype Server, the experiment controller initiated the call from the Dell desktop via the Skype Server. After the call was initiated and received by the "MLS Three" client, connectivity was established. Each test subject listened to File "C" at Station Three, by using a Plantronics PC Headset.

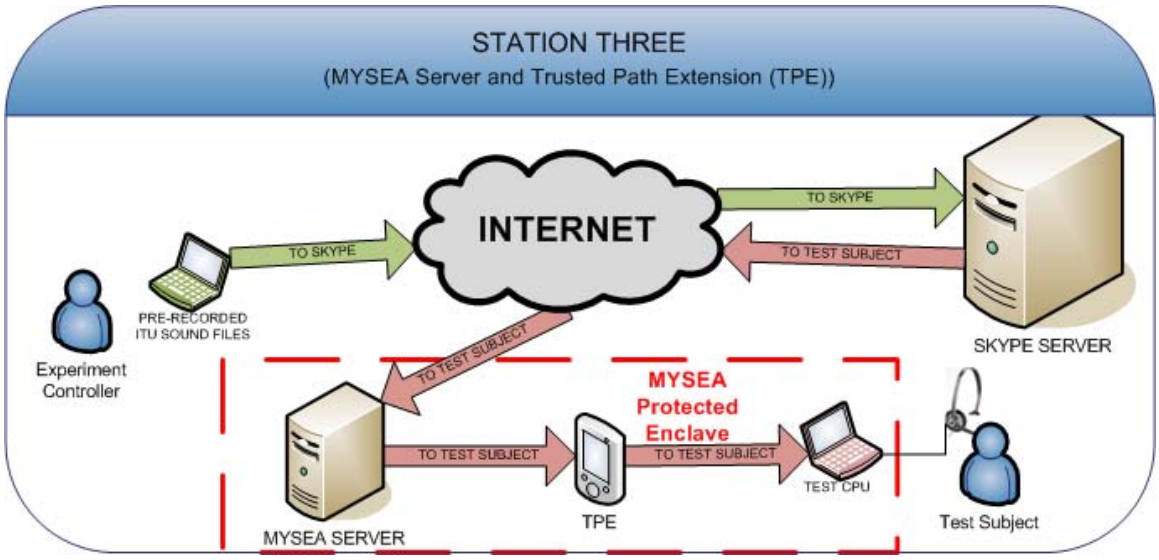

Figure 3. Station Three

8. Station Four

a. Equipment: Dell Inspiron Notebook CPU (5150); Plantronics PC Headset.

b. Network: Dell Desktop CPU (Dimension 8200) physically to the NPS Internet. The Dell Inspiron Notebook CPU (5150) is connected to a Trusted Path Extension (TPE), Dynamic Security Services Servers (Dell Dimension 8200), and the MYSEA Server (BAE XTS 400) and then into the NPS Internet using CAT 5 cabling.

c. Setup: ITU pre-recorded wave file played and transmitted from the experiment controller's desktop to the test subject's headset using Skype software.

d. Configuration: MYSEA, Dynamic Security Services (DSS)/Trusted Path Extension (TPE) Gateway Servers and Trusted Path Extension (TPE) are routed between Station Four and the Internet via NPS Internet. Figure 4 indicates Station Four is connected to the Internet via MYSEA using Skype software installed on the Dell Inspiron Notebook. Prior to testing, the experiment controller ensured the MYSEA server and the laptop were energized and logged onto the Internet. The experiment controller opened and activated the Skype account for "MLS Four" client. After logging onto to the Skype Server, the experiment controller initiated the call from the Dell desktop via the Skype Server. After the call was initiated and received by the "MLS Four" client, connectivity was established. Each test subject listened to File "D" at Station Four, by using a Plantronics PC Headset.

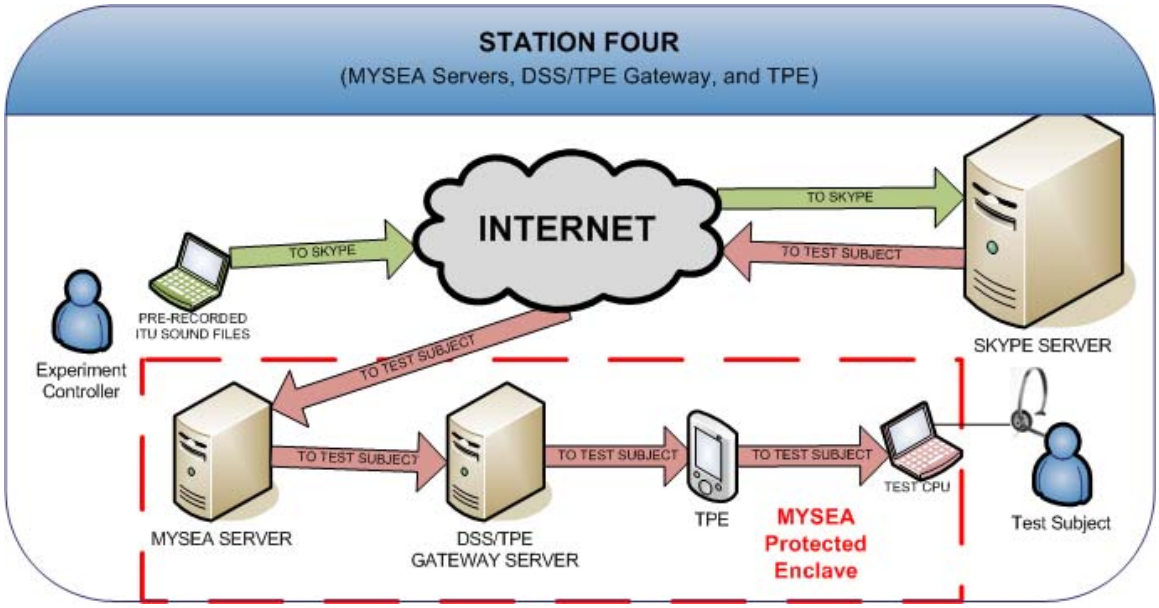

Figure 4. Station Four

9. Testing Procedures

a. Speech Material: The ITU sound files consisted of short speech passages, chosen at random from the ITU database of sample sound files which were simple and self-contained in meaning. Each sound file (segment) has a duration of not less than 9 seconds and not more than 15 seconds, and consists of two "sentences", which are separated by a pause of approximately 1 to 2 seconds. All sound files are of speech with a British accent, as recommended by ITU-T, and contained the phrases as shown in Appendix B. All sound files were played for each test subject over the Experiment Controller's Dell desktop via the RealPlayer Enterprise Player and transmitted over a pair of external computer speakers prior to commencing the testing. This procedure was performed to familiarize the test subjects with the accent, gender, configuration and length of each sound file. Additionally, each test subject was allotted ample time to review the questionnaire and become prepared to answer each question as thoroughly and completely as possible. No time limits were imposed for completion of each of the questionnaires.

b. Listening scale: The test subjects were instructed not to focus on the contents of the sentences but instead on the quality of sound. The rationale for this instruction, which was not conveyed to the participants, was that diversions regarding other aspects of the sound file could reduce the quality of the gathered information from the questionnaires, resulting in spurious assessment scores.

c. Procedures: A ten-item questionnaire was distributed and available at each station. Each test subject was afforded ample time to answer the questionnaire after listening to the recording one time. Figure 5 shows that each test subject rotated to the next station after completing their assigned station.

d. Period: Experimental sessions lasted from 30-35 minutes for completion of all four stations. Four test subjects simultaneously occupied each of the four stations and rotated through all four stations.

(1) Station transition: Approximately 1-2 minutes per test subject, per station; total transition time between stations for all test subjects is 4-8 minutes.

(2) Sound file transmission: approximately 1 minute per station; total sound file transmission time for all four stations is 4 minutes.

(3) Questionnaire completion time: 5-6 minutes per subject for the questionnaire at each station, which resulted in a 20-25 minute period for completing four questionnaires.

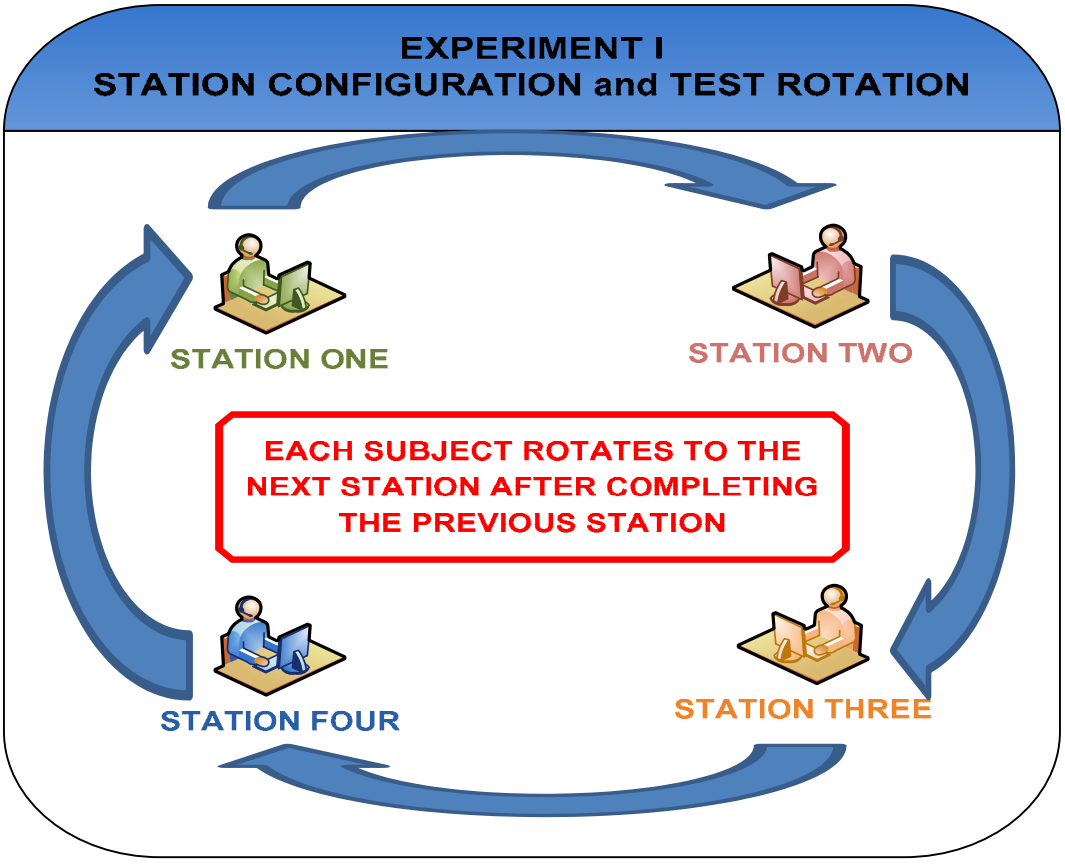

Figure 5. Station Configuration & Rotation

B. EXPERIMENT II

The objective of this experiment was to vary the order in which each of the four sound files were presented to the listener to determine if any sound files were of distinctly different quality than the others used in Experiment I. This experiment used the same standard sound files used in Experiment I. The sound files were transmitted to two separate test stations configured exactly the same using Skype software.[33] The two test configurations did not include components of the MYSEA infrastructure, and used the same configuration as Station One, Experiment I.

1. Subject Sampling

The test subjects were to listen and judge the four sound files in a pre-determined order, not known by the test subject, over two identically configured stations over identically configured networks and complete four separate ten-item questionnaires for each of the sound files.

All test subjects were random volunteers from the students and staff associated with the Naval Postgraduate School. The sample size of 40 test subjects was obtained from a total population of 1500 staff and students.[34] For a confidence level of 95% this sample size corresponds to a 15% confidence interval.[35]

Subjects were solicited through on-campus announcements which were posted at various academic buildings, email solicitations from academic advisors/professors and word of mouth by classmates. These methods were the basis of success in obtaining the required sample size for both experiments.

2. Test Question Selection

Testing methods were centered on the objective of obtaining a subjective performance assessment of the quality of sound of four separate sound files. The method

33 ITU-T Recommendation P.862 (2001) – Amendment 2.

34 Fred N. Kerlinger, Foundations of Behavioral Research, 3rd Edition, (CBS College Publishing, 1986), 117-119.

35 Creative Research Systems, The Survey System, http://www/surveysystem.com/sscalc.htm#ssneeded, [Accessed February 20, 2008]

was a "listening test" for sound file quality, where messages were presented aurally to all test subjects. Each test subject was given a ten-item questionnaire to answer after each sound file was played. Each of the test subject's opinion scores were rated on a cardinality rating scale of 0 to 5, with 5 being of greater quality (Appendix A). The cardinality point system was not known to the subject. These results were measures of the perceived quality in four categories of perception: Listening-quality effort; Articulation; Acceptance and Overall Impression. These areas made it possible to compare the effectiveness of different speech files over each of the two network configurations. The questionnaires used throughout both experiments (I and II) were the same and are included in Appendix A.[36]

3. Sound File Selection

ITU-T Recommendation P.862.3 was used to provide a guide for estimating listening speech quality by using reference sound files. This recommendation provides the necessary information for obtaining a stable and reliable reference for the listener's perception of speech quality.

It was recommended that the speech material consist of simple, short and meaningful sentences. These sentences were chosen to be easy to understand and were constructed into sets of two short sentences with no obvious connection of meaning between the sentences in a set. Additionally, in accordance with P.830, it was recommended that a minimum of two female and two male sound files be used for testing.[37]

4. Controlling Station

The experiment controller played the sample files for all test subjects prior to testing at each station for sound and accent familiarity. Additionally, he initiated all

36 ITU-T Recommendation P.85, Telephone Transmission Quality Subjective Opinion Tests, June 1994.

37 ITU-T Recommendation P.862.3, Telephone Transmission Quality, Telephone Installations, Local Line Networks, November 2005.

telephone connections between the controlling station and each of the testing stations via Skype VoIP software. The experiment controller used the same equipment for both Experiments I and II.

a. Equipment: Dell Desktop CPU (Dimension 8200); four individual ITU pre-recorded voice sound files, (two male, two female) played via RealPlayer Enterprise Player, Build: 6.0.11.1526, Copyright (c) 2004; (1) 4 ft, 3.5 mm stereo audio cable (Male/Male).

b. Network: Dell Desktop CPU connected to the Skype server via Naval Postgraduate School Internet (unclassified Internet).

c. Setup: A standard 3.5mm stereo audio cable (Male/Male) was connected to the speaker output jack (back of PC) and to the microphone input jack (back of PC) to create a loopback circuitry in order for the sound file to be transmitted to the Skype Server and back to the connected client.

NOTE: This testing was targeted for single connectivity, therefore, no conference calling features were tested or evaluated. All calls were made to one specific station at a time and only one file was transmitted over that connection.

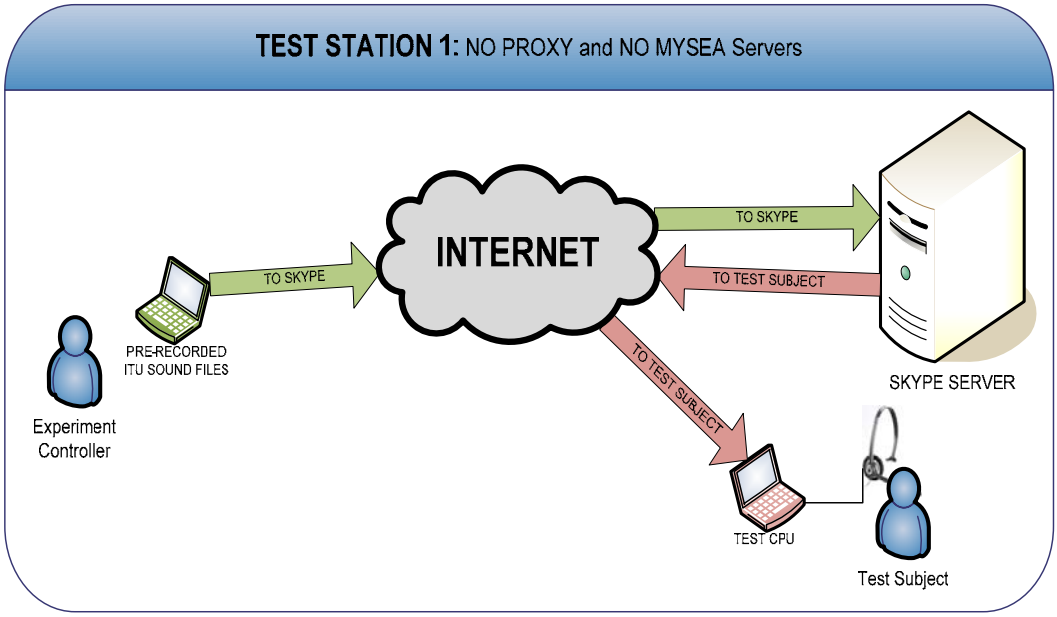

Figure 6. Test Station One (TS1) and Test Station Two (TS2)

5. Test Station One (TS1) and Test Station Two (TS2)

a. Equipment: Dell Inspiron Notebook CPU (5150); Plantronics PC Headset.

b. Network: Dell Desktop CPU (Dimension 8200) physically connected to the NPS Internet using CAT 5 cabling.

c. Setup: ITU pre-recorded wave file played and transmitted from the experiment controller's desktop to the test subject's headset using Skype software.

d. Configuration: As shown in Figures 6, Test Stations One and Two are connected directly to the Internet, via NPS Internet, using Skype software installed on the Dell Inspiron Notebook. Prior to testing, the experiment controller ensured that the laptop was logged on and connected to the Internet. After the experiment controller logged both test stations onto to the Skype Server, he initiated the call from the Dell desktop via the Skype Server. After the call was initiated, the "TS1" and "TS2" clients obtained connectivity. Various test subjects listened to the four sound files at Test Station One, by using a Plantronics PC Headset. The order in which each file was transmitted and played will be discussed in the "Testing Procedures".

6. Testing Procedures

a. Speech Material: The ITU sound files consisted of short speech passages, chosen at random from the ITU database of sample sound files and of which were simple and self-contained in meaning. Each sound file (segment) has a duration of not less than 9 seconds and not more than 15 seconds, and consists of two "sentences", which are separated by a pause of approximately 1 to 2 seconds. All sound files are of speech with a British accent, as recommended by ITU-T, as shown in Appendix B.

b. Configuration: All sound files were played for each test subject over the Experiment Controller's Dell desktop via the RealPlayer Enterprise Player and transmitted over a pair of external computer speakers prior to commencing the testing. This procedure was performed to familiarize the test

subjects with the accent, gender, configuration and length of each sound file. Additionally, each test subject was given ample time in reviewing the questionnaire in order to become prepared to answer the questions. No time limits were imposed on completing each of the questionnaires.

c. Listening scale: The test subjects were instructed not to focus on the contents of the sentences but instead on the quality of sound. The rational for this instruction, which was not conveyed to the participants, was that diversions regarding other aspects of the sound file could reduce the quality of the gathered information from the questionnaires, resulting in spurious assessment scores.

d. Procedures: Four (4) ten-item questionnaires were distributed and available at each of the two test stations. Each test subject was afforded ample time to answer the questionnaire after listening to each sound file. After completing the questionnaire for each sound file, the test subject indicated to the experiment controller that he/she was ready for the next sound file to be played. Sound files were played in a fixed order, as indicated in each "Trial" configuration. In Experiment II test subjects were tested on TS1 and TS2, simultaneously.

e. Period: Experimental sessions lasted from 25-30 minutes for completion of all four sound files. Two test subjects simultaneously occupied each of the two stations during playing of all four sound files for each Trial.

f. Sound file transmission: approximately 1 minute per station; total sound file transmission time: 1 minute per station, total sound file transmission time for both stations were 2 minutes.

g. Questionnaire completion time: 5-6 minutes per subject for the questionnaire at each station, which resulted in a 20-25 minute period for completing four questionnaires.

This experiment subjectively tested voice quality of Voice over Internet Protocol on four network configurations, using human test subjects. The outcome of Experiment I produced results that were unanticipated and required further testing to validate the

quality of each of the sound files. The ITU-T sound files needed to be evaluated by 40 test subjects not exposed to Experiment I. The conclusion of the Experiment II indicated that sound file “B” difference in quality from the other sound files.

IV. VOICE QUALITY ANALYSIS

A. SCOPE OF ANALYSIS

1. Introduction

This chapter presents the results of testing used to evaluate the audio quality of VoIP in the Monterey Secure Architecture (MYSEA). Single Attribute analysis is the primary analysis technique. This form of analysis consists of sampling a single attribute, i.e., voice quality, from the Mean Opinion Scores (MOS) derived from the ten-item questionnaire taken from subjective testing on four network configurations..[38] Additionally, "Multi-attribute analysis" which is a comparison of MOS results of two questions was used in the analysis of Experiment I.

In voice communication, audio quality usually dictates whether a listener's experience is either good or bad. A numerical method of expressing voice quality is required. The method used here is called the Mean Opinion Score (MOS). In this method, voice quality is measured by having randomly selected test subjects rate the quality of test sentences transmitted over a communications circuit.[39]

The Mean Opinion Score (MOS) technique accurately determines subjective results[40]. For this experiment, subjective testing required randomly selected test subjects to listen to pre-recorded standard files, and have them rate the audio quality according to their perception. To rate the audio quality, the test subjects were provided with a ten-item questionnaire. The questionnaire answers are presented in Appendixes C, and D.

The ten-item questionnaire conformed to a Mean Opinion Score by rating each response with a numerical value ranging from 0 to 5. A mapping of question answers to numerical scores is shown in Appendix A.

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38 Jay L. Devore, Probability and Statistics For Engineering and the Sciences 6th Edition, Brooks/Cole, 2004, 713.

39 ITU-T Recommendation P.862 (2001) – Amendment 2.

40 William C. Hardy, "VoIP Service Quality: Measuring and Evaluating Packet-switched Voice", McGraw-Hill Professional, 2003, 151.

At the conclusion of Experiment I, the results from one of the stations appeared anomalous. To identify any bias resulting from the quality of the sound file, all sound files used in Experiment I were tested for relative sound quality in Experiment II. This evaluation was performed using the same process as in Experiment I.

2. Analysis of Experiment I

Figures 1 through 6 in Chapter III present a pictorial representation of both experiments with four separate test configurations for Experiment I, and one configuration for Experiment II. The results were used for qualitative analysis of Voice over Internet Protocol (VoIP) in the MYSEA (Monterey Security Architecture) test bed using Skype, which is a commercial VoIP client and server software product. In Experiment I, each configuration is a separate station to be visited by each test subject. Each station added a component to the configuration for which voice quality in the test architecture was assessed. Station 1 and Station 2 measured the voice quality of VoIP in non-MYSEA networks, whereas, Stations 3 & 4 incorporated additional equipment (variables) from the MYSEA test bed network. A different sound file was selected to be transmitted to each of the test stations. (Appendix B identifies each sound file used at each specific station).

Completed questionnaires were collected and entered into an Excel spreadsheet for analysis by station and question, (see Tables 3-14 in Appendix C). These test questions were assigned the MOS scores (see Appendix A) and averaged to provide an overall MOS rating for each of the stations. As Chart 1 of Appendix C shows, Station Two displays a higher MOS rating than that the other three stations. This result was unexplainable based on the network configuration of Station Two.

Because Station One's network configuration (see Experimental Design Chapter, Figure 1) was the simplest, it was expected to have presented the best MOS score. Station Two's configuration, (see Experimental Design Chapter, Figure 2), included a "Proxy Server" and should have resulted in the same or decreased quality; instead, it displayed increased quality. Stations Three and Four provided MOS scores similar in perceived quality to Station One. Since a given sound file was always presented at a given station, it

was suspected that the sound file played at Station Two might be the cause of the observed anomaly. Experiment II was designed to examine this possibility.

a. Multi-attribute Analysis of Experiment I

Multi-attribute data analysis methods complement the single-attribute analysis. This process has been applied to the results of Experiment I in comparisons of two similar questions.[41] The goal of this analysis is to ascertain if two questions of similar meaning provide distinctive results when subjectively evaluating the quality of voice over internet protocol (VoIP) in a multilevel secure network.

The following areas were assessed:

1) Articulation: Perception on how clear the pronunciation of each spoken word (distinguish between words).

2) Acceptance: Indicates if the voice quality was found to be acceptable for telephone conversations.

3) Listening effort: The amount of effort required to understand the message.

4) Overall impression: Overall assessment of word clarity, system connection and background noise when listening to a telephone message.

Figures 4 through 15 (see Appendix E), are divided into four quadrants, representing the comparison between the two questions. Quadrant I (upper right corner), is represented with green color signifying “good” sound quality; Quadrants II, IV (lower right and upper left, respectively) are yellow signifying “neutral” sound quality, and Quadrant III (lower left) is pink signifying “bad” or “poor” sound perception of the test subjects responses.

This methodology of analysis reinforces the single-attribute analysis of the questions asked in reference to voice quality, sound quality and word clarity. Utilizing multi-attribute by comparing two similar questions and plotting the results into a quadratic graph, illustrates how the test subjects perceived quality of each of the sound files at the various stations.

41 F. Murtagh and A. Heck, Multivariate Data Analysis, Kluwer, Dordrecht, 1987

3. Question 3 / Question 4

The first multi-attribute analysis of two questions:

Question 3: *The voice on the recording was*:

- I Don't remember or I'm not sure = 0
- Fading = 1
- Low Volume = 2
- Clear = 3

Question 4: *The voice of the person on the recording sounded: Was it like an echo/hollow, fuzzy/unnatural or was it clear and understandable?*

- I Don't remember or I'm not sure = 0
- Fuzzy/Unnatural = 1
- Echo/Hollow = 2
- Clear and Understandable = 3

4. Question 9 / Question 1

The second multi-attribute analysis of two questions:

Question 9: *How would you rate the quality of the sound of what you have just heard?*

- I Don't remember or I'm not sure = 0
- Bad = 1
- Poor = 2
- Fair = 3
- Good = 4
- Excellent = 5

Question 1: *Which of these four words comes closest to describing the quality of the connection during the recording?*

- Poor = 1
- Fair = 2
- Good = 3
- Excellent = 4

5. Question 10 / Question 5

The third and final multi-attribute analysis of two questions:

Question 10: *Were all of the words distinguishable?*

- o I Don't remember or I'm not sure = 0
- o No, Not at all = 1
- o No, Not very clear = 2
- o Fairly Clear = 3
- o Yes, Clear enough = 4
- o Yes, Very Clear = 5

Question 5: *Did you find certain words hard to understand?*

- o I Don't remember or I'm not sure = 0
- o Often = 1
- o Occasionally = 2
- o Rarely = 3
- o Never = 4

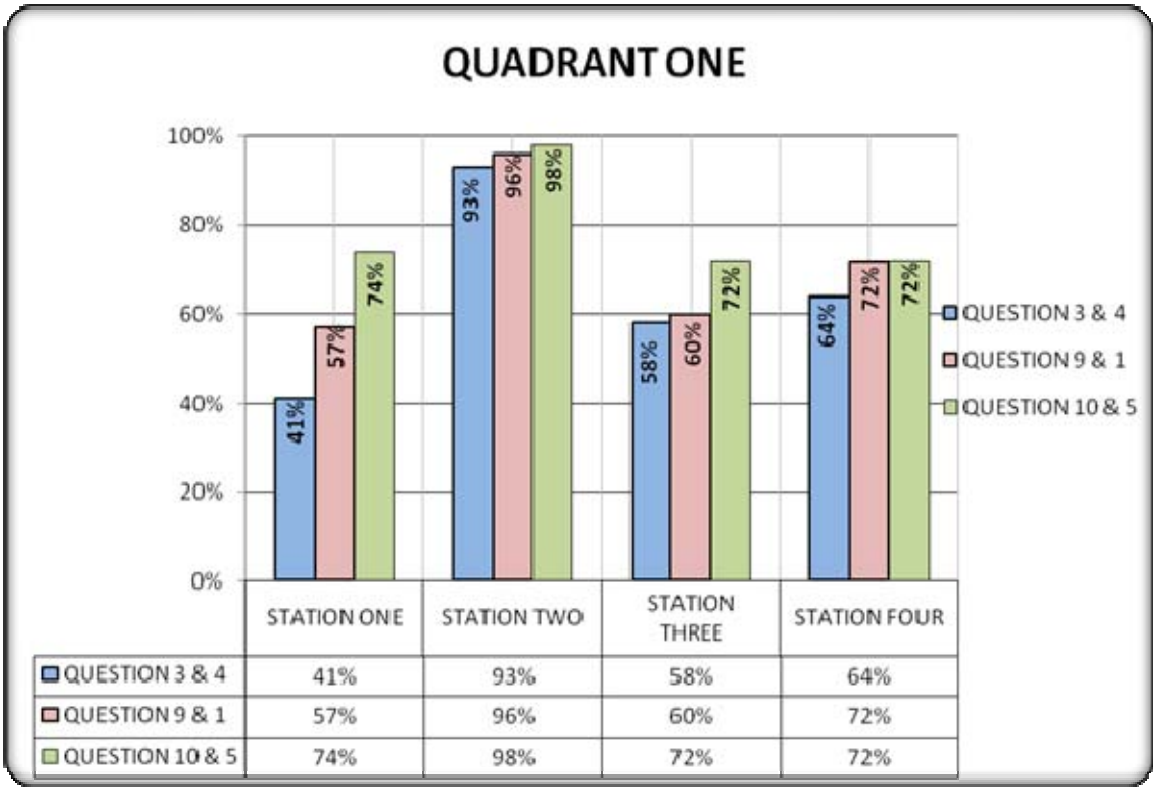

Figure 7. Multi-Attribute Comparison of All Question Pairs

The Multi-attribute analysis supports the results of the single attribute analysis as indicated in Figure 7. Station Two received much higher quadrant one scores than any of the other stations.

6. Analysis of Experiment II

The objective of this experiment was to vary the order in which the four sound files were presented to a listener with a fixed network configuration to determine if one sound file was of better quality than the others. This experiment used the same ITU-T standard sound files as were used in Experiment I. The sound files were transmitted to two separate test stations configured exactly the same using Skype software.[42] Forty randomly and newly selected test subjects participated in Experiment II. Unlike Experiment I, each questionnaire distributed requested the gender of the Test Subject. This information was to help identify any listener/speaker gender bias.

42 ITU-T Recommendation P.862 (2001) – Amendment 2.

Experiment II was designed to rotate the order in which each the sound files were presented:

Trial 1: A, B, C, D

Trial 2: B, C, D, A

Trial 3: C, D, A, B

Trial 4: D, A, B, C

Appendix D, Chart 7 shows, each sound file tabulated by the test subject's gender in order to determine if the anomalous scores in Experiment I, Station Two, could have come from gender biasing. Since the effect of test subject gender on the results were negligible, gender biasing was determined not to have been a factor in the anomalous outcome for Experiments I or II. Each question response was tabulated in Tables 16 through 31. These responses were averaged and compared as displayed in Charts 9 through 12 of Appendix D.

Figure 8 shows that Station Two in Experiment I exhibited significantly higher scores than the other three stations. Additional testing was required to determine if sound file biasing was the cause of the anomalous reading.

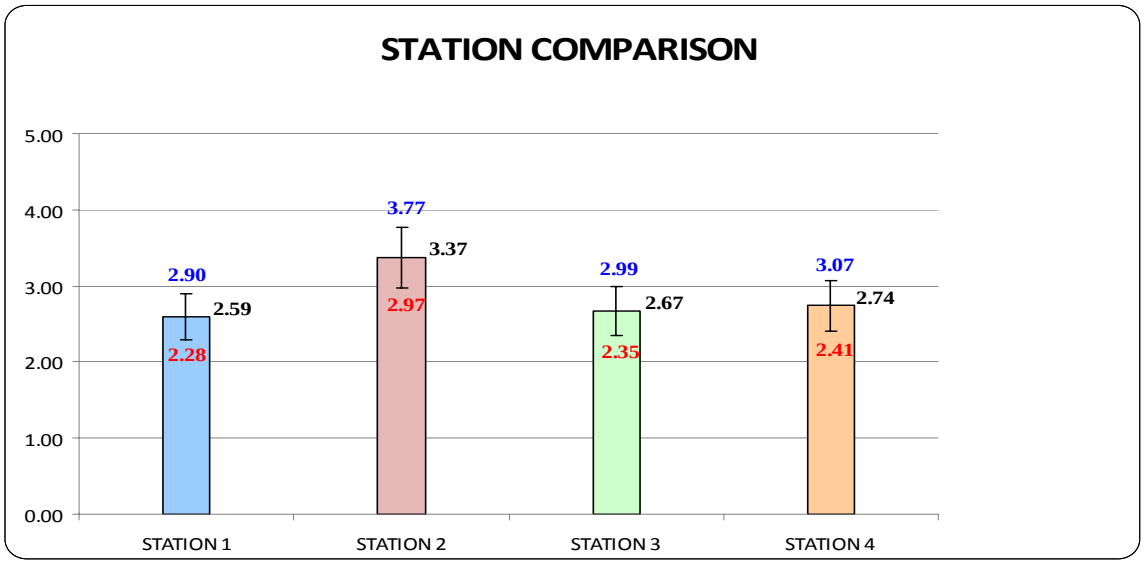

Figure 8. Station Comparison with Upper/Lower Confidence limits

Figure 9 confirms that the anomalous result for Experiment I resulted from sound file quality; in Experiment II. The higher sound quality of File B was consistent with the higher sound quality measured for Station Two in Experiment I; indicating that the increase was due to the quality of the sound file as perceived by test subjects and not because of the network configuration of Station Two.

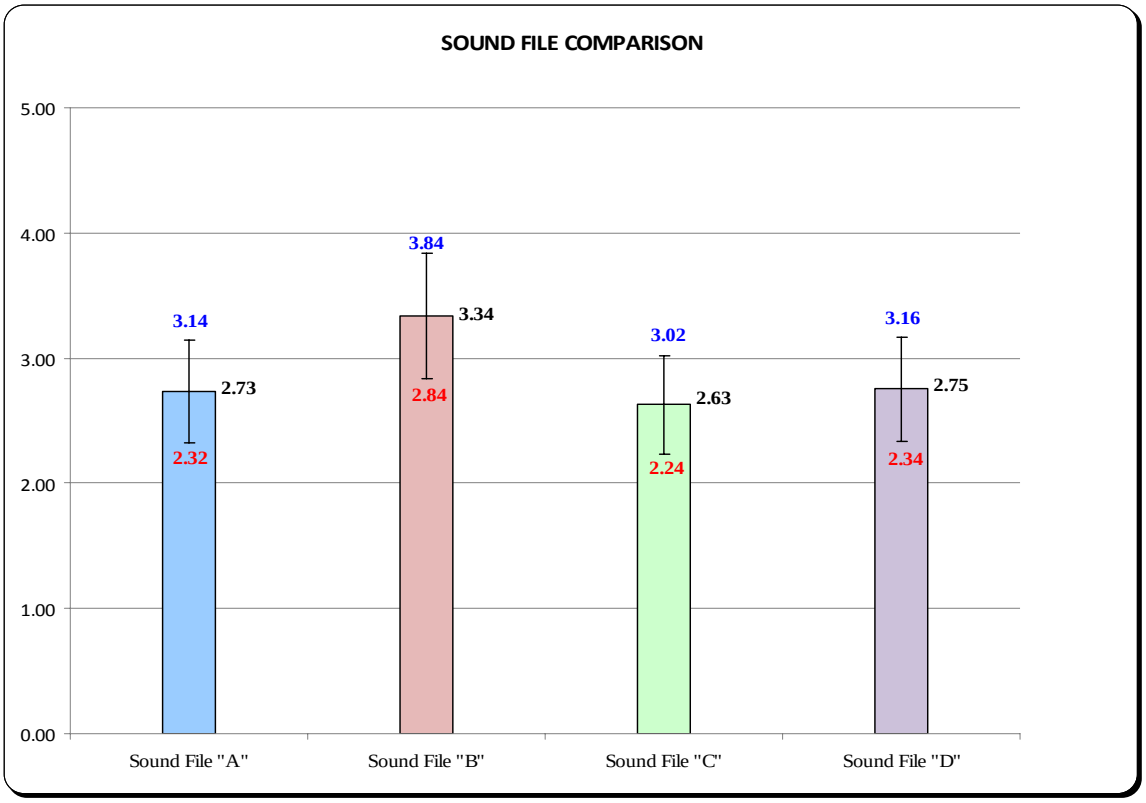

Figure 9. Experiment II Sound File Comparison

V. CONCLUSION

This thesis explored the quality of Voice over Internet Protocol (VoIP) when configured within a multilevel secure network and compared it to voice quality within a non-multilevel secure network. The standards of the Telecommunication Standardization Sector (ITU-T), P.862.3, were used for testing of voice quality within VoIP signals in a controlled and isolated multilevel network.[43]. The Monterey Secure Architecture, MYSEA, was the test bed multilevel secure network, where VoIP software, Skype, was used to transmit the sound files. This call processing software was used for all experiments and on all test stations.

The test subjects consisted of staff and students from the Naval Postgraduate School. Each test subject was instructed on Skype's operational capability and functionality. Additionally, they were instructed to listen to the four sound files and complete a ten-item questionnaire for each sound file which were assigned to a specific testing station. Experiment I was configured for the test subjects to evaluate the sound files at each of four network configurations. Each station questionnaire was graded and tabulated using a Mean Opinion Score (MOS), which was used for single and multi attribute analysis. Once the MOS was scored and plotted, an anomalous result appeared for Station Two. Since a particular sound file was always presented at a particular station, it was suspected that the sound file played at Station Two might be the cause of the observed anomaly. Experiment II was designed to examine the possibility of sound file bias.

The objective of Experiment II was to determine if one sound file was of better quality than the others. This was achieved by varying the order in which the four sound files were presented to each listener within a fixed network configuration. Using the same ITU-T standard sound files as were used in Experiment I, all sound files were transmitted to two separate test stations configured exactly the same, as shown in Figure 6, using Skype software.[44] Forty test subjects participated in Experiment II. The questionnaires

43 ITU-T Recommendation P.862 (2001) – Amendment 2.

44 ITU-T Recommendation P.862 (2001) – Amendment 2.

for Experiment II requested the gender of each Test Subject. This information was to help identify any listener/speaker gender bias. Experiment II rotated the order in which each of the sound files was presented as outlined in the Experimental Design Chapter.

Test subject gender showed negligible differences on the results of Experiment II. Thus test subject gender bias was dismissed as a factor in the anomalous outcome for Station Two in Experiment I. Experiment II results provided evidence that the sound file "B" had scores indicating a statistically significant anomalous outcome.

All of Station Two results provided in Experiment I were disregarded and Station One was used as the baseline for the remaining testing and analysis. The experimental results indicate that voice quality in multilevel secure networks scored as "good" or "better" voice quality when compared to the same characteristics in a non-multilevel secure network.

APPENDIX A. QUESTIONNAIRE

Appendix A lists the ten-item questionnaire administered to participants in both Experiments (I & II) after they listened to each of the sound files.

Each question is assigned a point value for analysis computation.

Table 1. Ten Item Questionnaire

	QUESTIONS	CARDINALITY POINT ASSIGNMENT					
		0	1	2	3	4	5
1	*Which of these four words comes closest to describing the quality of the connection during the recording?*		POOR	FAIR	GOOD	EXCELLENT	
2	*Did you have difficulty in listening over the connection*		YES		NO		
3	*The voice on the recording was:*	I DON'T REMEMBER I'M NOT SURE	FADING	LOW VOLUME	CLEAR		
4	*The voice of the person on the recording sounded: Was it like an echo/hollow, fuzzy/unnatural or was it clear and understandable?*	I DON'T REMEMBER I'M NOT SURE	FUZZY / UNNATURAL	ECHO / HOLLOW	CLEAR AND UNDERSTAND-ABLE		
5	*Did you find certain words hard to understand?*	I DON'T REMEMBER I'M NOT SURE	OFTEN	OCCASIONALLY	RARELY	NEVER	
6	*How would you describe the effort you were required to make in order to understand the message?*	NOT COMPRE-HENSIBLE WITH ANY EFFORT	EFFORT REQUIRED	MODERATE EFFORT REQUIRED	ATTENTION NECESSARY; NO APPRECIABLE EFFORT REQUIRED	COMPLETELY COMPREHENSIBLE; NO EFFORT REQUIRED	

Table 1. Ten Item Questionnaire (cont)

QUESTIONS		CARDINALITY POINT ASSIGNMENT					
		0	1	2	3	4	5
7	*Tell me if you noticed any of these during your session: A rushing or hissing sound; a frying and /or sizzling, crackling sound; or a humming or buzzing sound?*	I DON'T REMEMBER I'M NOT SURE	HUMMING, BUZZING	FRYING AND/OR SIZZLING, CRACKLING	RUSHING, HISSING	I DIDN'T NOTICE ANY NOISE OR ANYTHING OTHER THAN THE RECORDING	
8	*Please try to remember the background noise in the area around your station (e.g., noise from the air-conditioning unit, office equipment, or other people talking) while you were involved in the testing. Which of the following categories best describes your experience?*	I DON'T REMEMBER I'M NOT SURE	VERY NOISY	NOISY	QUIET	VERY QUIET	
9	*How would you rate the quality of the sound of what you have just heard?*	I DON'T REMEMBER I'M NOT SURE	BAD	POOR	FAIR	GOOD	EXCELLENT
10	*Were all of the words distinguishable?*	I DON'T REMEMBER I'M NOT SURE	NO, NOT AT ALL	NO, NOT VERY CLEAR	FAIRLY CLEAR	YES, CLEAR ENOUGH	YES, VERY CLEAR

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APPENDIX B. SOUND FILES

The International Telecommunications Union Standardization Sector (ITU-T) provided sound files were used in end-to-end speech quality assessment of telephone networks.

1. Sound file **"A"**: British female voice (af1s03b2c17) with the words:

   "He took out his pipe and lit up. It was a separate bar."

2. Sound file **"B"**: British male voice (am1s03b2c4) with the words:

   "He carried a bag of tennis balls. The scheme was plotted out."

3. Sound file **"C"**: British female voice (af1s01b2c16) with the words:

   "You were the perfect Hostess. Are you going to be nice to me?"

4. Sound file **"D"**: British male voice (am1s02b2c4) with the words:

   "There wasn't a scrap of evidence. The jar was full of water."

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APPENDIX C. EXPERIMENT I DATA

Appendix C shows questionnaire data from each of the 61 test subjects taken during Experiment I.

Table 2. Station Average MOS Scores

AVERAGE DATA COMPARISON										
STATIONS/QUESTIONS	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**
STATION ONE AVERAGE (S1)	2.70	2.31	2.30	1.93	2.25	2.20	3.05	2.51	3.59	3.10
STATION TWO AVERAGE (S2)	3.52	2.93	2.97	2.79	3.36	3.38	3.64	2.64	4.30	4.20
STATION THREE AVERAGE (S3)	2.82	2.31	2.49	2.00	2.30	2.36	3.23	2.44	3.67	3.10
STATION FOUR AVERAGE (S4)	2.85	2.41	2.64	2.15	2.54	2.43	3.07	2.48	3.62	3.25

Table 2 is the average scores for each question for each station. See Appendix A for Mean Opinion Score (MOS) point assignment to questionnaire complete sentences.

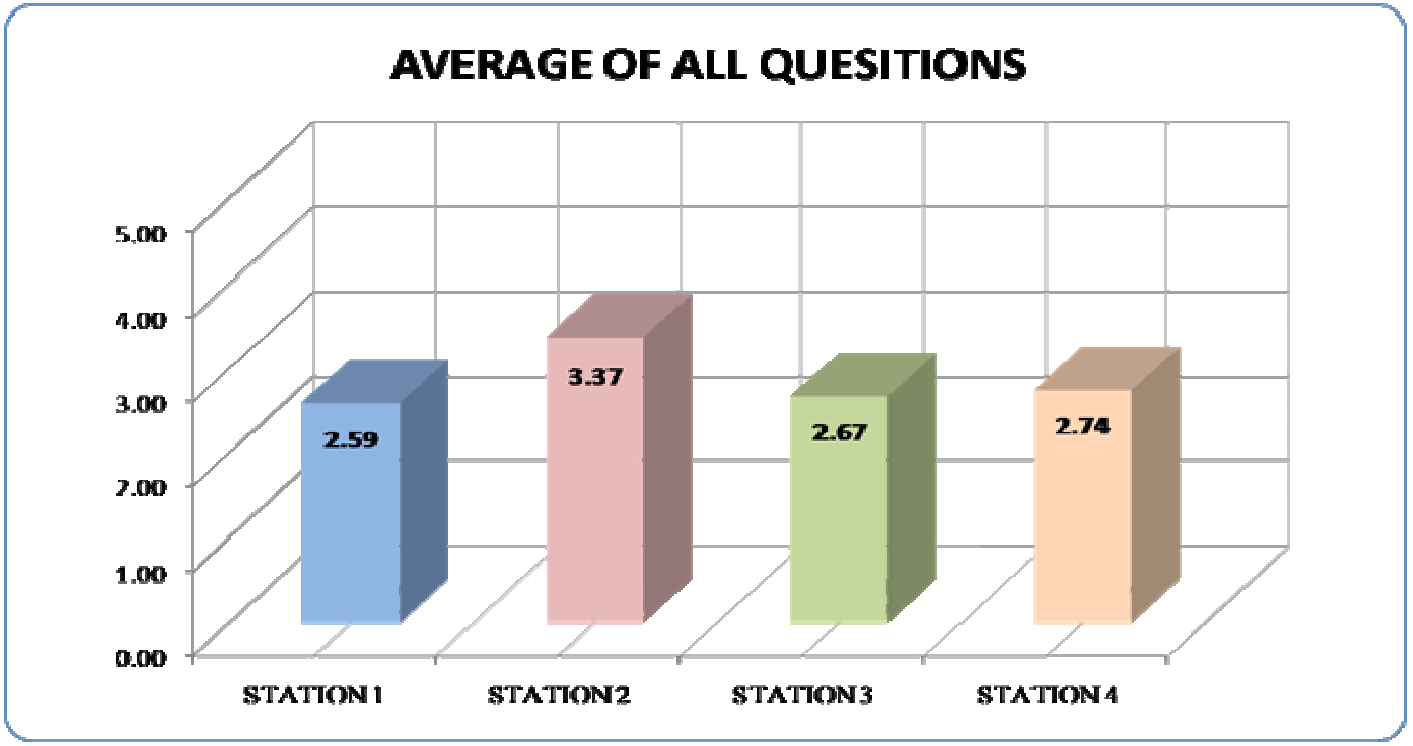

Chart 1. Station Comparison of All Questions

Chart 1 compares the average score for all question for each station .

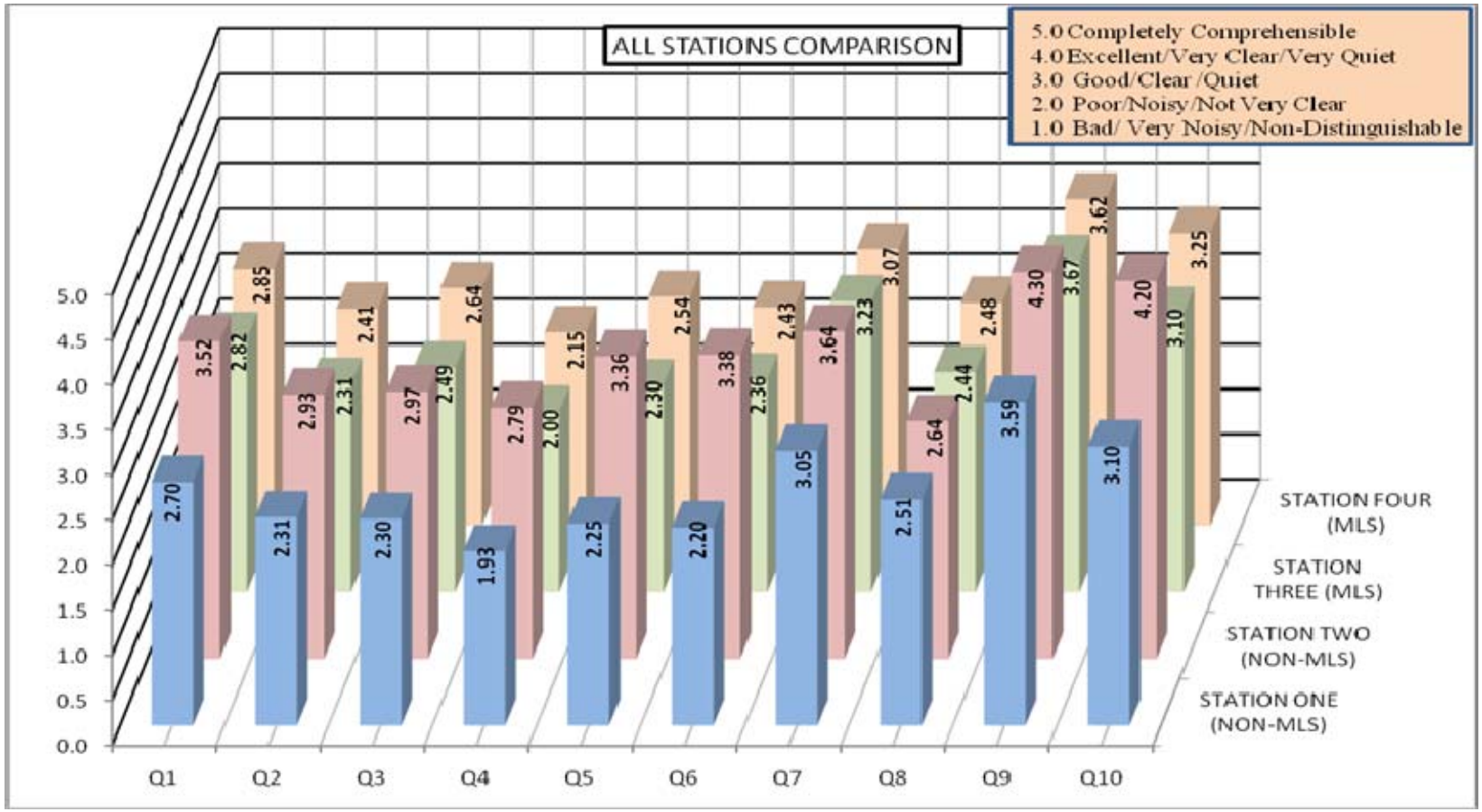

Chart 2. Stations and Question Comparison

Chart 2 shows the comparison of each station by each individual question. The Mean Opinion Score value assigned is detailed in the information box in the upper right corner of Chart 2.

Table 3. Station One Raw Data

TEST STATION One	SURVEY QUESTIONS									
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Test Subject 1	2	3	1	2	2	3	2	2	3	4
Test Subject 2	2	1	3	1	2	1	3	2	3	2
Test Subject 3	1	1	2	1	1	0	3	2	2	1
Test Subject 4	4	3	3	3	2	1	4	2	5	2
Test Subject 5	4	3	3	3	1	1	4	2	5	1
Test Subject 6	1	1	1	1	1	1	3	4	3	2
Test Subject 7	2	3	3	1	2	2	1	2	3	3
Test Subject 8	3	3	1	1	2	3	4	2	3	3
Test Subject 9	4	3	3	3	3	3	4	2	5	4
Test Subject 10	2	1	3	1	2	2	4	2	3	3
Test Subject 11	3	3	3	3	3	4	4	2	4	4
Test Subject 12	4	3	3	3	3	3	4	3	4	4
Test Subject 13	1	1	1	1	1	0	0	3	3	1
Test Subject 14	3	3	3	3	2	1	4	2	4	4
Test Subject 15	1	1	2	1	1	0	0	3	2	1
Test Subject 16	3	3	3	3	2	2	0	2	4	3
Test Subject 17	2	1	2	1	2	3	4	2	3	3
Test Subject 18	2	1	1	1	1	1	2	2	2	2
Test Subject 19	4	3	3	3	2	4	4	4	5	5
Test Subject 20	2	1	2	1	2	1	2	3	3	3

Table 4. Station One Raw Data (cont)

TEST STATION One	SURVEY QUESTIONS									
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Test Subject 21	2	3	1	2	2	2	2	2	3	2
Test Subject 22	2	3	1	1	2	3	4	3	4	3
Test Subject 23	3	3	1	3	2	3	4	3	4	3
Test Subject 24	3	1	1	1	2	3	4	4	4	3
Test Subject 25	3	3	3	3	2	3	4	2	4	3
Test Subject 26	3	3	3	3	3	3	4	3	4	3
Test Subject 27	2	3	1	3	4	4	2	3	3	4
Test Subject 28	2	1	2	1	1	1	2	2	2	2
Test Subject 29	4	1	3	1	3	3	4	3	4	4
Test Subject 30	4	3	3	3	2	3	4	2	4	4
Test Subject 31	3	3	3	1	2	2	4	3	3	3
Test Subject 32	2	3	3	1	4	3	4	2	3	4
Test Subject 33	3	3	2	1	4	3	1	2	4	4
Test Subject 34	2	1	0	1	2	1	0	3	2	2
Test Subject 35	4	3	3	3	3	2	4	3	5	4
Test Subject 36	3	3	3	3	2	1	4	2	4	4
Test Subject 37	2	1	3	1	2	2	2	2	3	3
Test Subject 38	4	3	3	3	4	4	3	2	5	5
Test Subject 39	3	1	3	1	2	2	4	3	3	3
Test Subject 40	3	3	1	2	2	3	4	2	4	3

Table 5. Station One Raw Data (cont)

TEST STATION One	SURVEY QUESTIONS									
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Test Subject 41	3	3	3	3	4	3	2	2	4	4
Test Subject 42	4	3	3	3	3	4	4	2	5	4
Test Subject 43	3	3	3	1	3	3	4	2	3	3
Test Subject 44	3	1	1	1	2	2	3	3	3	3
Test Subject 45	3	3	3	3	2	2	4	4	4	4
Test Subject 46	2	1	3	1	1	0	2	3	3	2
Test Subject 47	3	3	3	1	1	1	4	3	4	2
Test Subject 48	1	3	3	3	1	1	4	2	5	3
Test Subject 49	3	3	3	3	3	3	4	2	4	4
Test Subject 50	2	1	1	1	2	1	4	2	3	3
Test Subject 51	4	3	3	3	2	3	4	2	5	3
Test Subject 52	2	3	1	1	2	1	2	2	3	3
Test Subject 53	3	3	3	3	2	1	4	3	3	3
Test Subject 54	4	3	3	3	4	4	4	3	5	5
Test Subject 55	2	1	1	1	2	3	3	3	3	2
Test Subject 56	3	3	3	3	3	3	4	2	4	4
Test Subject 57	4	3	3	3	4	4	0	3	4	4
Test Subject 58	3	3	2	1	3	2	3	3	4	4
Test Subject 59	2	3	3	3	2	3	3	3	4	3
Test Subject 60	2	1	1	1	2	1	0	3	2	3
Test Subject 61	2	1	2	1	2	2	4	2	3	2

Tables 3, 4 and 5 show the responses from the 61 test subjects who listened to Sound File “A” at Station One.

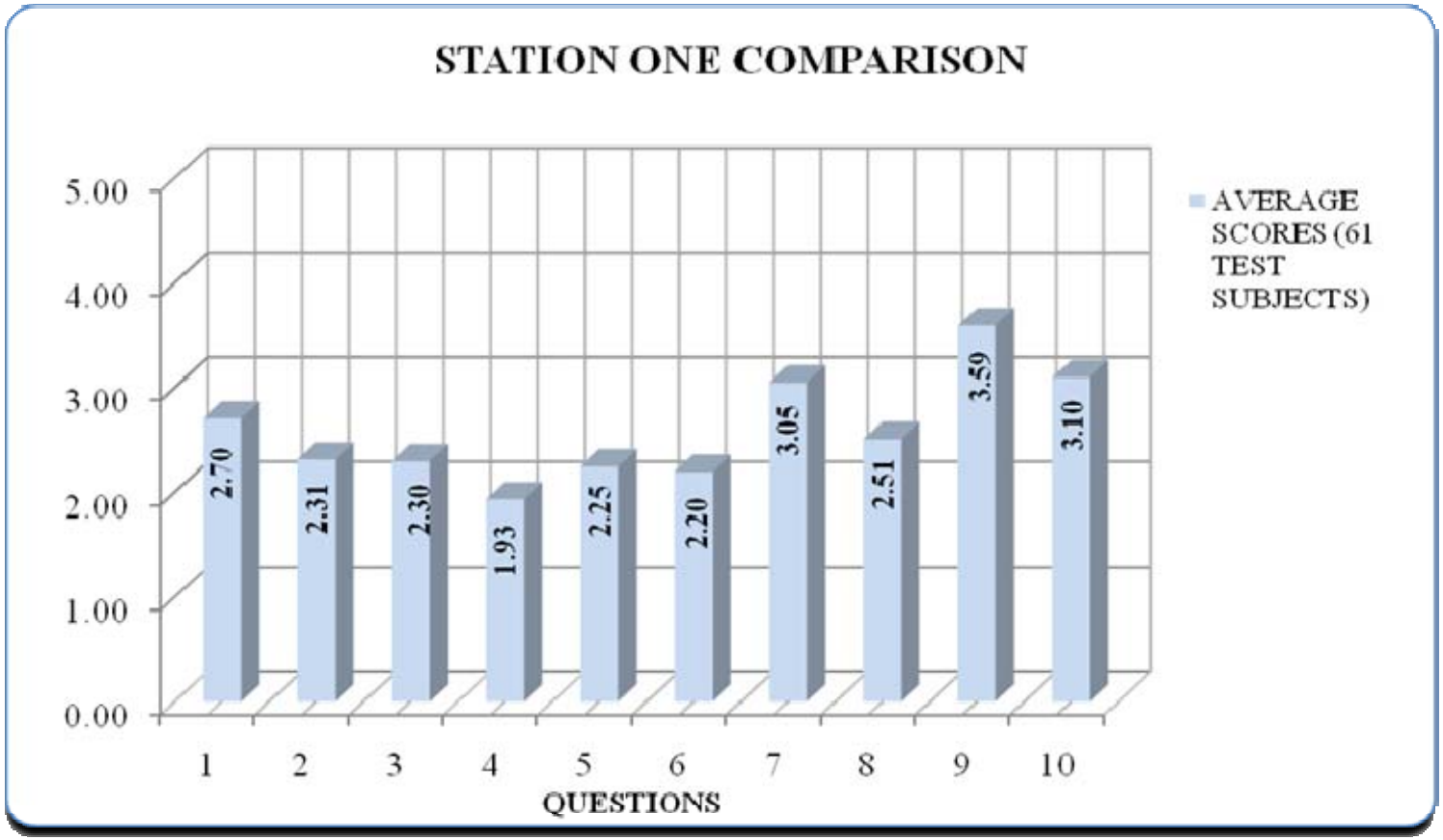

Chart 3. Station One Average Question Responses

Chart 3 shows the average scores of 61 test subjects on the ten item questionnaire at Station One.

Table 6. Station Two Raw Data

TEST STATION Two	SURVEY QUESTIONS									
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Test Subject 1	3	3	3	2	3	2	1	2	4	4
Test Subject 2	4	3	3	3	4	4	4	2	4	5
Test Subject 3	3	3	3	3	3	2	1	2	4	3
Test Subject 4	4	3	3	3	4	4	4	2	5	5
Test Subject 5	4	3	3	3	4	3	4	2	5	4
Test Subject 6	4	3	3	3	4	4	4	4	5	5
Test Subject 7	2	3	3	2	3	3	1	3	3	4
Test Subject 8	4	3	3	3	4	4	4	2	4	4
Test Subject 9	4	3	3	3	3	3	4	2	5	4
Test Subject 10	3	3	3	1	4	3	4	2	4	4
Test Subject 11	3	3	3	0	4	3	2	1	4	4
Test Subject 12	4	3	3	3	4	4	4	4	5	5
Test Subject 13	4	3	3	3	4	4	4	3	4	5
Test Subject 14	4	3	3	3	3	3	4	2	4	4
Test Subject 15	3	3	3	3	2	3	4	3	4	4
Test Subject 16	4	3	3	3	2	3	4	2	4	3
Test Subject 17	4	3	3	3	3	3	4	2	4	4
Test Subject 18	4	3	3	3	4	3	4	4	5	3
Test Subject 19	4	3	3	3	4	4	4	4	5	5
Test Subject 20	4	3	3	3	2	3	4	3	5	4

Table 7. Station Two Raw Data (cont)

TEST STATION Two	SURVEY QUESTIONS									
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Test Subject 21	3	3	3	2	2	3	3	2	4	4
Test Subject 22	4	3	3	3	4	4	4	3	5	5
Test Subject 23	4	3	3	3	4	4	4	4	5	5
Test Subject 24	4	3	3	3	4	4	4	4	5	5
Test Subject 25	3	3	3	3	3	4	4	2	5	4
Test Subject 26	4	3	3	3	4	3	4	4	4	4
Test Subject 27	4	3	3	3	4	4	4	4	5	5
Test Subject 28	3	3	3	3	4	4	4	2	4	4
Test Subject 29	3	1	3	3	3	3	4	3	4	4
Test Subject 30	4	3	3	3	4	4	4	2	4	5
Test Subject 31	3	3	3	3	2	3	4	3	3	3
Test Subject 32	4	3	3	3	4	4	4	2	5	5
Test Subject 33	4	3	3	3	3	3	4	2	5	4
Test Subject 34	3	3	3	3	3	4	4	3	4	4
Test Subject 35	4	3	3	3	4	4	4	3	5	5
Test Subject 36	4	3	3	3	4	4	4	2	5	4
Test Subject 37	3	3	3	1	3	3	2	2	3	3
Test Subject 38	4	3	3	3	4	4	4	2	5	5
Test Subject 39	3	3	3	3	2	3	3	3	4	3
Test Subject 40	4	3	3	3	4	4	4	2	5	4

Table 8. Station Two Raw Data (cont)

TEST STATION Two	SURVEY QUESTIONS									
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Test Subject 41	4	3	3	3	4	4	4	2	5	5
Test Subject 42	3	3	3	3	4	4	4	2	4	4
Test Subject 43	1	1	1	1	1	1	2	2	2	2
Test Subject 44	3	3	3	3	3	3	4	4	4	4
Test Subject 45	3	3	3	3	4	3	4	4	4	5
Test Subject 46	4	3	3	3	3	4	4	3	4	4
Test Subject 47	4	3	3	3	2	4	4	3	4	4
Test Subject 48	4	3	3	3	4	4	4	2	5	5
Test Subject 49	3	3	3	3	4	4	4	2	4	5
Test Subject 50	3	3	3	3	2	2	2	2	3	3
Test Subject 51	4	3	3	3	4	3	4	2	5	5
Test Subject 52	3	3	3	3	4	3	4	2	4	4
Test Subject 53	3	3	3	3	2	2	4	3	3	4
Test Subject 54	4	3	3	3	4	4	4	3	5	5
Test Subject 55	3	3	3	2	2	3	4	3	4	3
Test Subject 56	4	3	3	3	4	4	4	2	4	4
Test Subject 57	3	3	3	3	3	3	3	3	4	4
Test Subject 58	4	3	3	3	4	4	4	3	5	5
Test Subject 59	4	3	3	3	4	4	4	4	5	5
Test Subject 60	3	3	3	3	3	3	4	3	4	4
Test Subject 61	3	3	3	3	3	2	2	2	4	4

Tables 6, 7, and 8 show the responses from the 61 test subjects who listened to Sound File “B” at Station Two.

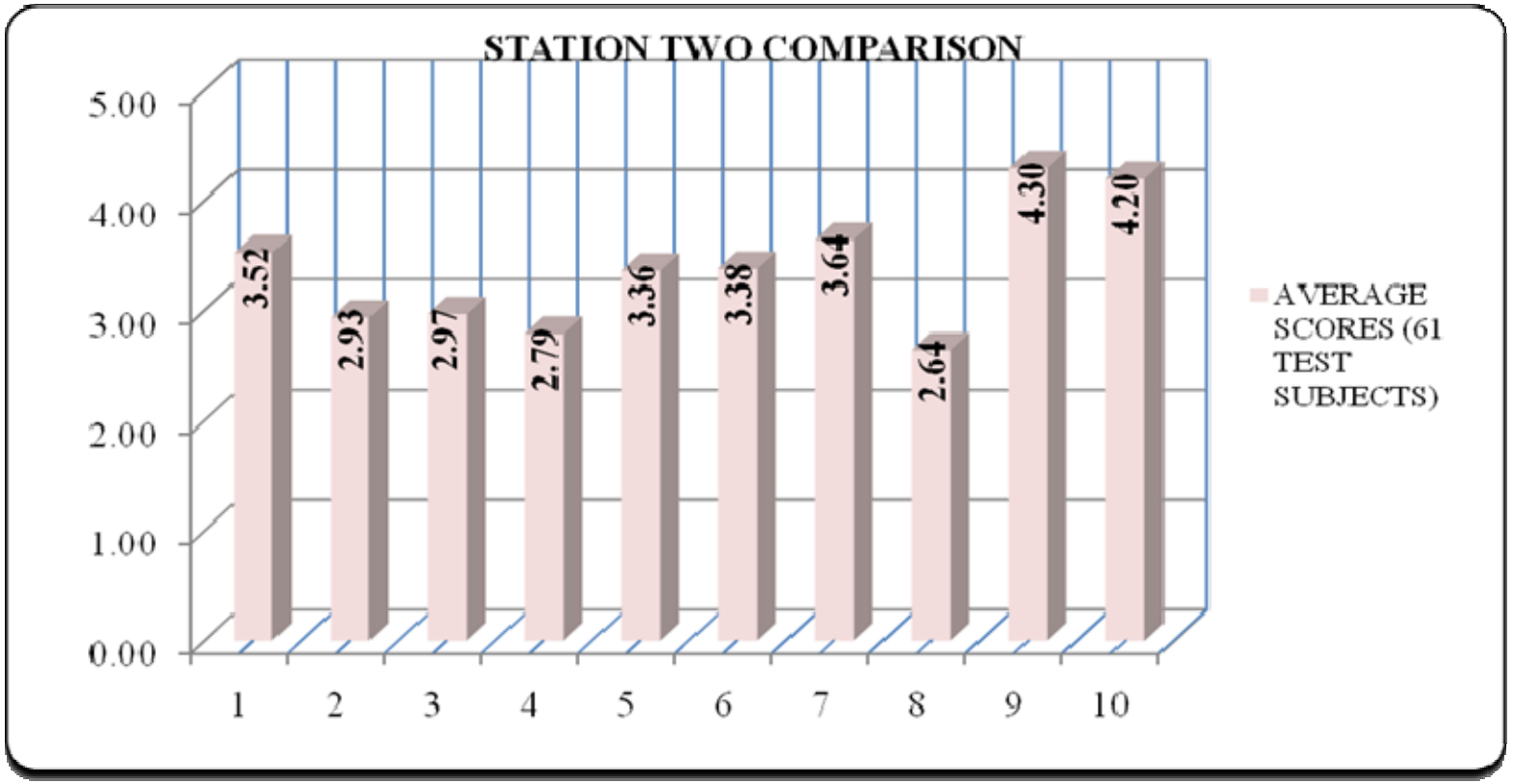

Chart 4. Station Two Average Question Responses

Chart 4 shows the average scores of 61 test subjects on the ten item questionnaire at Station Two.

Table 9. Station Three Raw Data

TEST STATION Three	SURVEY QUESTIONS									
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Test Subjects 1	2	1	1	2	2	2	1	2	2	2
Test Subjects 2	2	3	0	1	2	1	2	2	2	2
Test Subjects 3	2	1	3	2	1	1	4	2	4	4
Test Subjects 4	3	3	3	3	2	1	4	2	5	2
Test Subjects 5	4	3	3	3	4	3	4	2	5	4
Test Subjects 6	2	1	3	1	2	2	4	4	5	3
Test Subjects 7	2	3	3	2	2	1	1	3	2	3
Test Subjects 8	4	3	3	0	2	3	4	2	4	4
Test Subjects 9	3	3	3	3	2	3	4	2	4	4
Test Subjects 10	3	3	3	1	2	2	4	2	4	3
Test Subjects 11	2	1	3	1	2	2	2	1	3	3
Test Subjects 12	2	1	2	1	2	2	3	2	3	3
Test Subjects 13	2	1	3	2	2	3	2	3	3	3
Test Subjects 14	4	3	3	3	3	3	4	2	5	4
Test Subjects 15	2	1	0	1	1	1	3	3	3	2
Test Subjects 16	2	1	3	1	1	1	2	2	2	1
Test Subjects 17	3	1	3	1	2	2	4	2	4	3
Test Subjects 18	4	3	3	3	3	4	4	3	5	4
Test Subjects 19	3	3	3	3	2	3	4	4	4	4
Test Subjects 20	3	3	3	2	2	3	4	3	3	3

Table 10. Station Three Raw Data (cont)

TEST STATION Three	SURVEY QUESTIONS									
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Test Subjects 21	3	3	1	3	2	3	2	2	4	3
Test Subjects 22	2	1	3	1	2	3	2	3	3	3
Test Subjects 23	2	3	2	1	3	3	2	2	3	4
Test Subjects 24	4	3	3	3	4	4	4	4	5	5
Test Subjects 25	3	3	3	3	3	3	4	2	5	4
Test Subjects 26	2	3	3	1	2	3	3	2	3	3
Test Subjects 27	3	3	3	2	4	4	3	3	4	4
Test Subjects 28	3	3	3	3	4	4	4	2	4	4
Test Subjects 29	3	1	3	1	2	2	4	3	3	3
Test Subjects 30	4	3	3	3	2	3	4	2	5	4
Test Subjects 31	4	3	3	3	4	4	4	3	4	4
Test Subjects 32	3	3	3	3	4	4	4	2	4	5
Test Subjects 33	3	3	3	1	3	3	1	2	4	3
Test Subjects 34	3	3	3	2	2	1	4	3	4	2
Test Subjects 35	4	3	3	3	4	4	4	3	5	5
Test Subjects 36	3	3	3	3	2	3	4	2	3	3
Test Subjects 37	2	3	3	2	2	2	2	2	3	3
Test Subjects 38	4	3	3	3	3	3	4	2	5	3
Test Subjects 39	2	1	0	1	1	1	3	3	3	2
Test Subjects 40	3	1	1	1	2	3	3	2	3	3

Table 11. Station Three Raw Data (cont)

TEST STATION Three	SURVEY QUESTIONS									
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Test Subjects 41	4	3	3	3	2	2	4	2	4	2
Test Subjects 42	2	1	1	1	2	2	3	2	3	2
Test Subjects 43	3	1	3	2	2	2	4	2	3	3
Test Subjects 44	2	1	3	2	2	2	3	3	3	2
Test Subjects 45	2	3	1	1	4	3	2	2	3	4
Test Subjects 46	2	1	1	2	2	2	4	3	4	3
Test Subjects 47	3	3	3	3	1	0	4	3	4	2
Test Subjects 48	4	3	3	3	1	1	4	2	5	2
Test Subjects 49	3	3	3	3	4	3	4	2	4	3
Test Subjects 50	2	1	1	2	1	1	3	2	2	2
Test Subjects 51	2	1	3	2	1	0	3	2	3	2
Test Subjects 52	2	3	1	1	1	1	4	2	3	1
Test Subjects 53	3	3	3	3	2	2	4	3	4	3
Test Subjects 54	3	3	3	1	2	3	4	3	4	3
Test Subjects 55	3	3	3	2	2	2	4	3	4	3
Test Subjects 56	4	3	3	3	4	4	4	2	5	5
Test Subjects 57	3	3	3	3	3	3	4	3	4	4
Test Subjects 58	4	3	3	2	2	1	3	3	4	3
Test Subjects 59	3	3	3	1	3	4	3	3	4	4
Test Subjects 60	2	1	1	2	2	2	0	3	3	3
Test Subjects 61	2	1	1	1	1	1	0	2	2	2

Tables 9, 10, and 11 show the responses from the 61 test subjects who listened to Sound File “C” at Station Three.

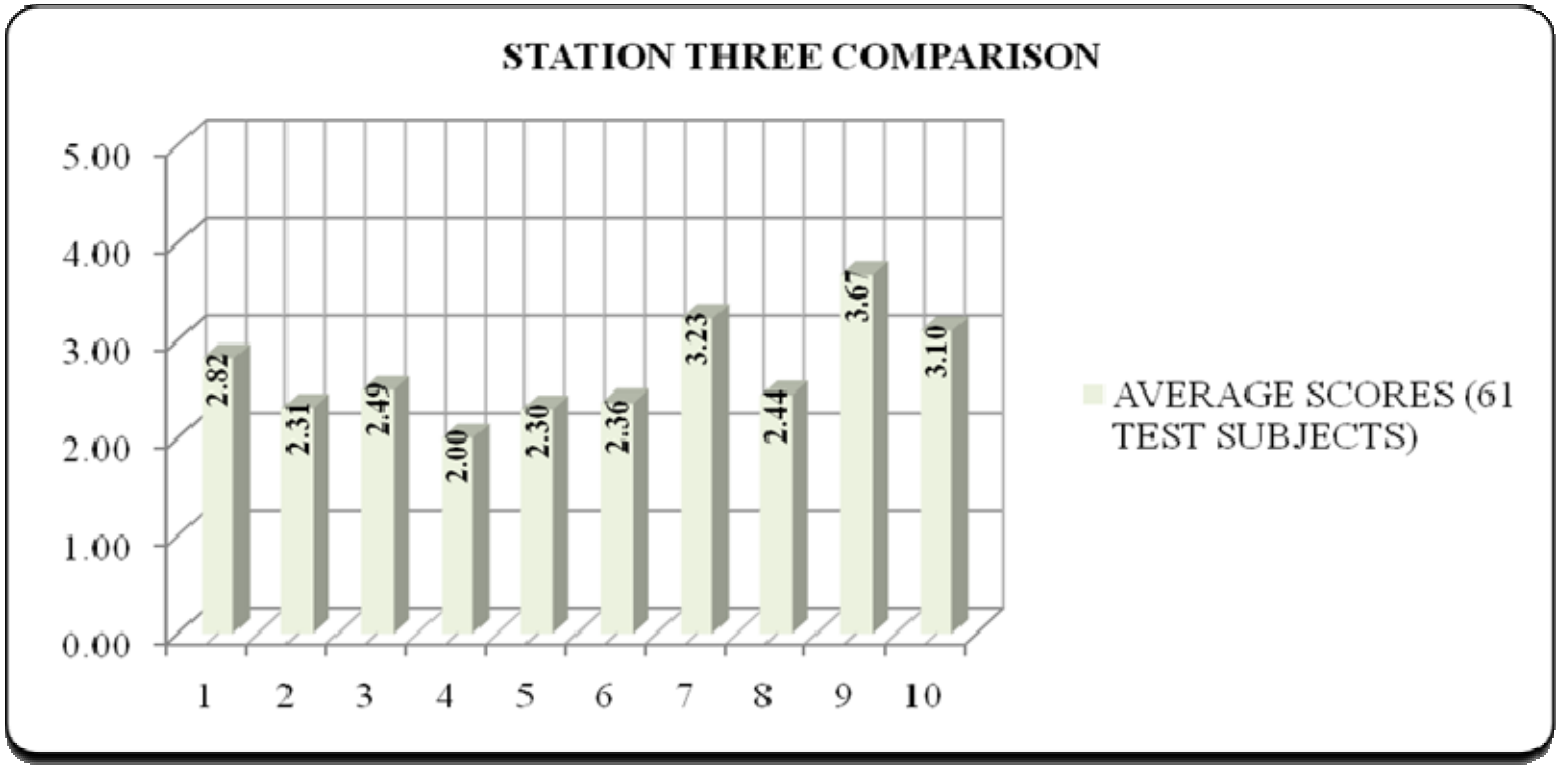

Chart 5. Stations Three Average Question Responses

Chart 5 shows the average scores of 61 test subjects on the ten item questionnaire at Station Three.

Table 12. Station Four Raw Data

TEST STATION Four	SURVEY QUESTIONS									
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Test Subject 1	3	3	3	3	4	3	4	2	5	4
Test Subject 2	3	3	3	1	3	3	4	2	4	3
Test Subject 3	3	3	3	3	3	2	4	2	4	4
Test Subject 4	4	1	3	3	2	2	2	2	3	3
Test Subject 5	4	3	3	3	3	3	4	2	5	4
Test Subject 6	3	3	3	1	3	2	2	3	5	3
Test Subject 7	1	1	1	1	1	1	1	2	1	1
Test Subject 8	3	3	1	1	2	2	4	2	3	3
Test Subject 9	3	3	3	3	3	3	4	2	4	4
Test Subject 10	3	3	3	2	3	3	4	2	4	3
Test Subject 11	2	1	3	1	2	2	1	1	3	2
Test Subject 12	4	3	3	3	3	3	4	4	5	5
Test Subject 13	4	3	3	3	4	4	4	3	5	5
Test Subject 14	4	3	3	3	3	3	4	2	5	4
Test Subject 15	3	3	3	0	3	2	1	3	3	3
Test Subject 16	2	1	3	1	1	1	2	2	2	1
Test Subject 17	3	3	3	3	3	3	4	2	4	4
Test Subject 18	3	1	3	3	2	3	1	3	4	2
Test Subject 19	1	1	2	1	1	0	3	3	2	2
Test Subject 20	4	3	3	3	2	4	4	3	4	4

Table 13. Station Four Raw Data (cont)

TEST STATION Four	SURVEY QUESTIONS									
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Test Subject 21	3	3	3	3	2	3	4	2	4	4
Test Subject 22	2	1	1	1	2	2	3	3	3	2
Test Subject 23	3	3	3	2	2	3	3	3	4	3
Test Subject 24	3	3	3	3	3	3	4	4	4	4
Test Subject 25	4	3	3	3	4	4	4	2	5	5
Test Subject 26	3	3	3	3	3	3	4	3	4	4
Test Subject 27	4	3	3	3	4	4	3	3	5	4
Test Subject 28	3	3	3	3	3	2	4	2	4	3
Test Subject 29	3	1	3	1	2	3	4	3	4	3
Test Subject 30	4	3	3	3	4	4	4	2	5	5
Test Subject 31	3	3	3	3	3	3	4	3	4	4
Test Subject 32	3	3	3	1	4	4	4	2	4	5
Test Subject 33	2	1	3	2	2	2	3	2	3	3
Test Subject 34	2	1	1	1	2	3	0	3	3	3
Test Subject 35	4	3	3	3	4	3	4	3	5	5
Test Subject 36	3	3	3	3	3	3	4	2	4	4
Test Subject 37	1	3	3	1	1	1	2	2	2	2
Test Subject 38	4	3	3	2	4	4	2	2	5	5
Test Subject 39	2	1	0	1	2	2	3	3	3	3
Test Subject 40	2	1	1	1	2	2	2	2	2	2

Table 14. Station Four Raw Data (cont)

TEST STATION Four	SURVEY QUESTIONS									
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Test Subject 41	2	1	1	1	1	1	1	2	2	1
Test Subject 42	3	3	3	3	3	3	3	2	4	3
Test Subject 43	1	1	3	2	1	1	4	2	1	2
Test Subject 44	2	1	3	1	1	1	3	3	2	1
Test Subject 45	3	3	3	2	4	3	0	3	3	4
Test Subject 46	4	3	3	3	3	3	0	3	5	4
Test Subject 47	3	3	3	3	1	1	2	3	4	2
Test Subject 48	3	3	3	3	2	2	4	2	4	3
Test Subject 49	3	3	3	3	4	4	4	2	4	4
Test Subject 50	3	3	2	3	3	2	4	2	3	3
Test Subject 51	3	1	3	1	2	1	3	2	3	3
Test Subject 52	2	3	1	2	2	1	3	2	3	2
Test Subject 53	3	3	3	3	2	2	4	3	4	3
Test Subject 54	3	3	3	3	2	3	4	3	4	4
Test Subject 55	3	3	3	2	2	3	4	3	4	4
Test Subject 56	3	3	3	3	4	3	4	2	4	4
Test Subject 57	1	1	1	1	1	0	2	2	1	1
Test Subject 58	3	3	3	1	1	0	1	3	4	2
Test Subject 59	4	3	3	3	4	4	4	4	5	5
Test Subject 60	2	3	3	2	3	2	4	3	3	4
Test Subject 61	2	1	2	1	2	1	3	2	2	2

Tables 12, 13, and 14 show the responses from the 61 test subjects who listened to Sound File “D” at Station Four.

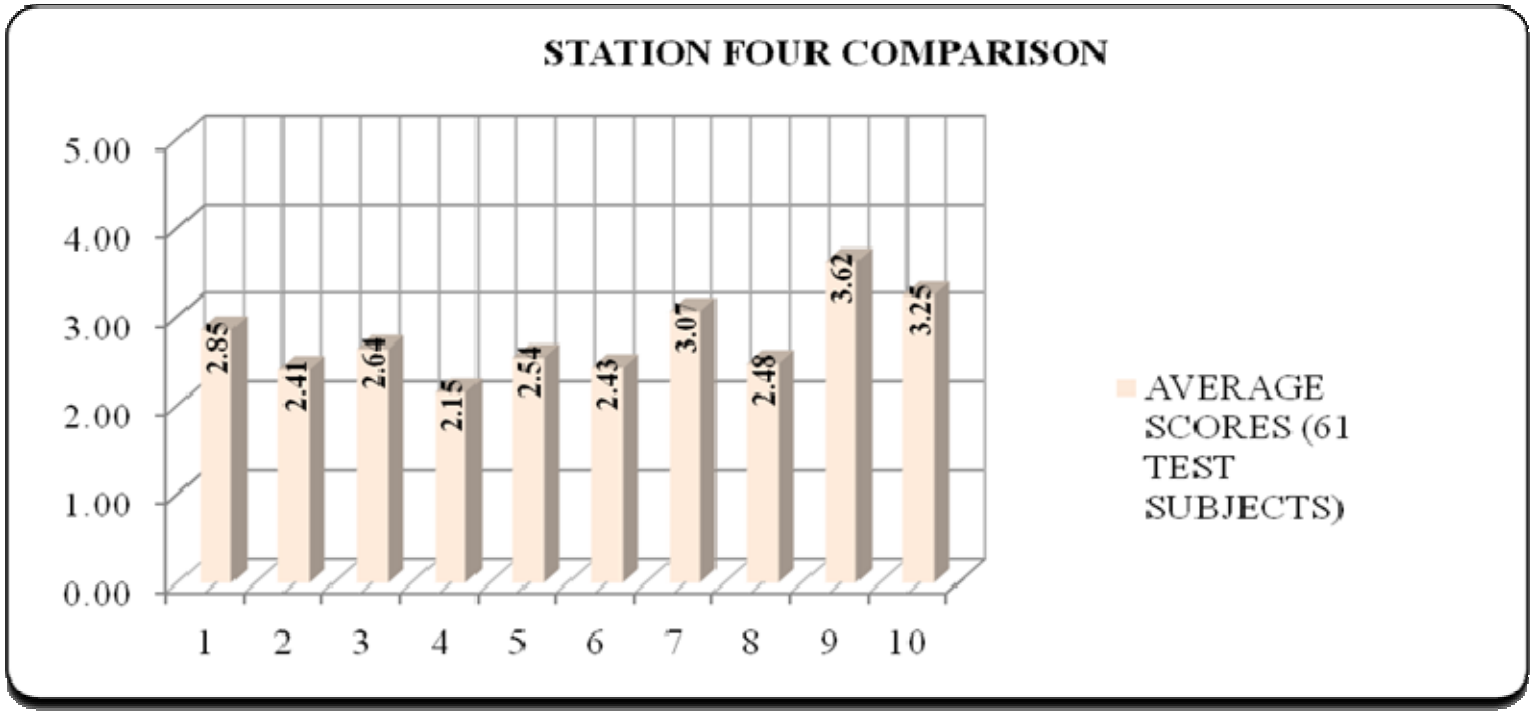

Chart 6. Station Four Average Question Responses

Chart 6 shows the average scores of 61 test subjects on the ten item questionnaire at Station Four.

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APPENDIX D. EXPERIMENT II DATA

Appendix D provides questionnaire data from each of the 40 test subjects taken during Experiment II.

Table 15. Average questionnaire scores as a function of sound files.

AVERAGE DATA COMPARISON										
FILES/QUESTIONS	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**
SOUND FILE "A"	2.85	2.75	2.50	1.90	2.50	2.80	3.18	2.35	3.43	3.10
SOUND FILE "B"	3.53	2.90	2.95	2.75	3.53	3.43	3.38	2.30	4.38	4.25
SOUND FILE "C"	2.83	2.50	2.45	2.15	2.15	2.40	3.05	2.25	3.48	3.03
SOUND FILE "D"	3.05	2.60	2.68	2.13	2.45	2.63	2.85	2.35	3.68	3.13

Table 15 is the average scores for each question for each sound file. See Appendix A for point assignment to questionnaire complete sentences.

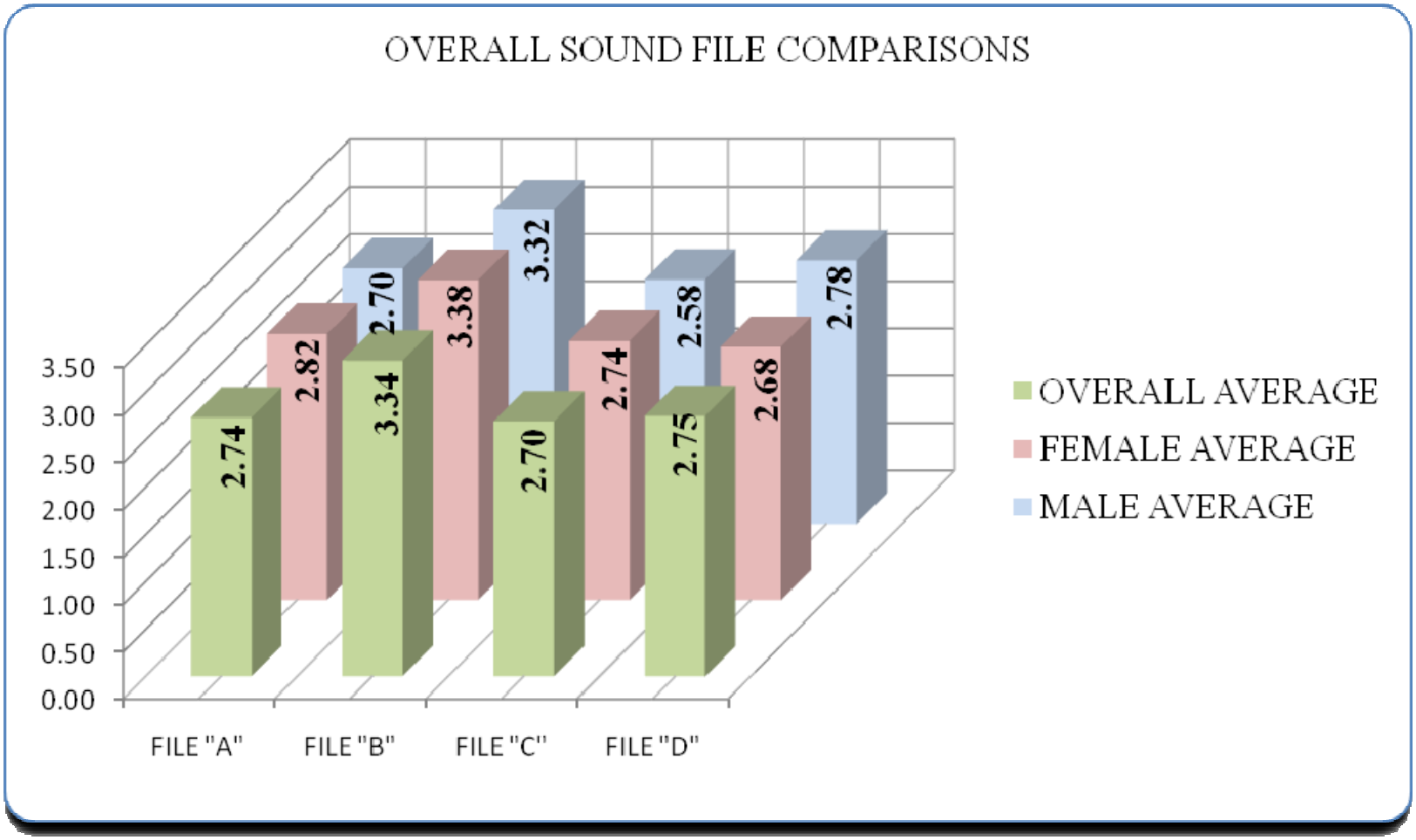

Chart 7. Average scores are shown as a function of the listener gender.

Chart 7 Shows the average score for each sound file.

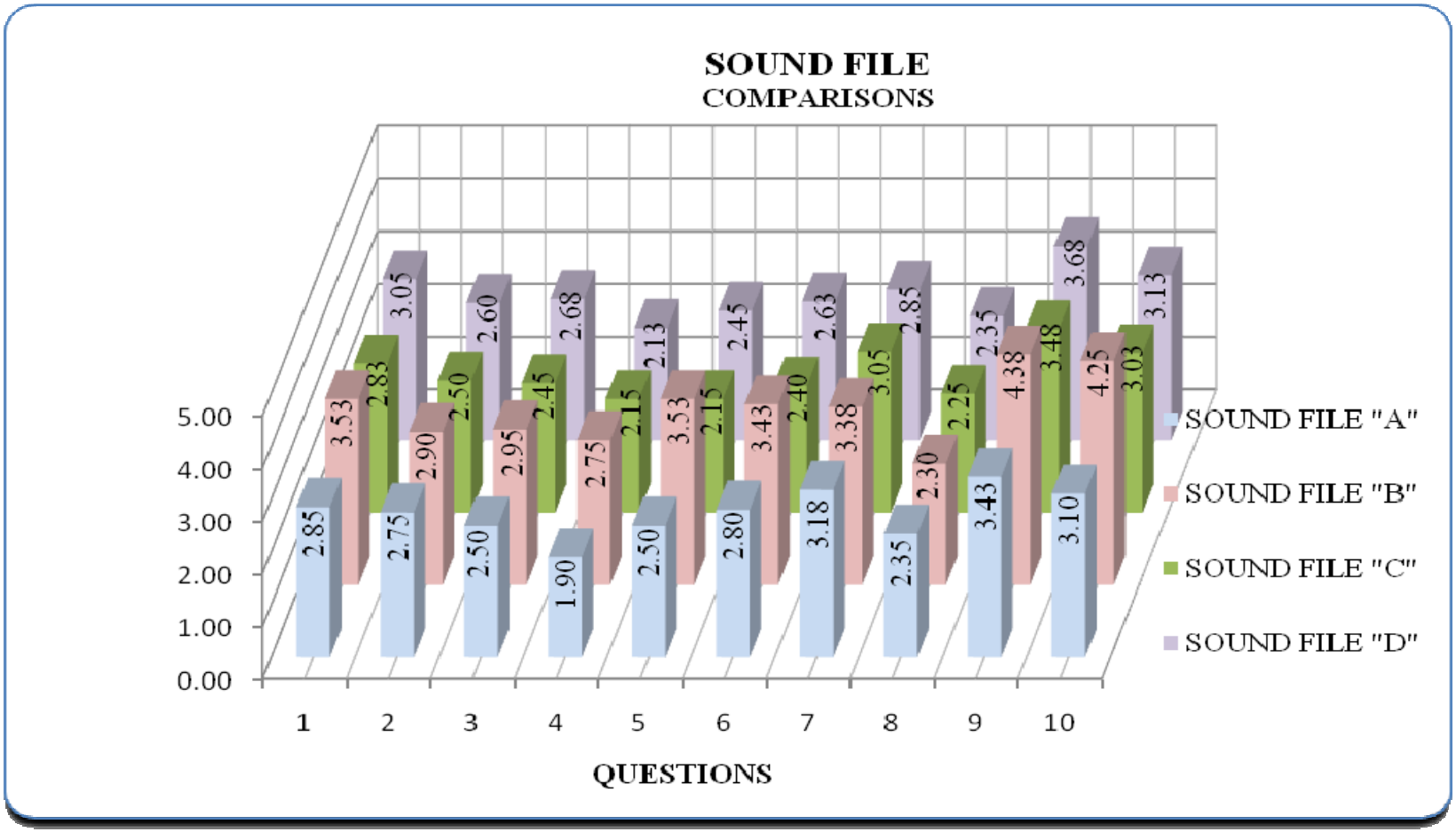

Chart 8. All Sound File Comparison

Chart 8 shows the average responses for each question for each sound file.

Table 16. Trial 1 Sound File "A" Raw Data

SOUND FILE "A"	SURVEY QUESTIONS									
	SF_AQ_1	SF_AQ_2	SF_AQ_3	SF_AQ_4	SF_AQ_5	SF_AQ_6	SF_AQ_7	SF_AQ_8	SF_AQ_9	SF_AQ_{10}
Trial 1-1	2	3	3	1	2	3	4	2	3	3
Trial 1-2	2	3	3	3	2	3	3	2	3	3
Trial 1-3	3	3	3	3	2	3	4	2	4	3
Trial 1-4	3	3	3	3	4	3	4	3	4	4
Trial 1-5	3	3	3	3	2	3	4	2	4	4
Trial 1-6	1	1	1	1	1	1	2	2	2	1
***Trial 1-7**	2	3	1	1	2	3	4	3	3	3
Trial 1-8	3	3	1	2	3	3	2	2	4	3
Trial 1-9	2	1	3	2	2	2	4	2	3	2
***Trial 1-10**	3	3	3	2	3	3	2	2	3	4

Note: * Indicates Female Test Subject Response

Sound file **"A"**: British female voice (af1s03b2c17) with the words: *"He took out his pipe and lit up. It was a separate bar."*

Table 17. Trial 1 Sound File "B" Raw Data

SOUND FILE "B"	SURVEY QUESTIONS									
	SF_BQ_1	SF_BQ_2	SF_BQ_3	SF_BQ_4	SF_BQ_5	SF_BQ_6	SF_BQ_7	SF_BQ_8	SF_BQ_9	SF_BQ_{10}
Trial 1-1	4	3	3	3	4	4	4	2	5	4
Trial 1-2	3	3	3	3	4	4	4	2	4	5
Trial 1-3	4	3	3	3	3	3	4	2	4	4
Trial 1-4	4	3	3	3	4	4	4	3	5	4
Trial 1-5	4	3	3	3	3	4	4	2	5	4
Trial 1-6	3	1	3	2	2	2	1	2	3	3
***Trial 1-7**	3	3	3	3	4	4	4	3	5	5
Trial 1-8	4	3	3	3	4	4	4	3	5	5
Trial 1-9	4	3	3	3	3	2	4	2	4	3
***Trial 1-10**	3	3	3	2	3	3	2	2	4	4

Note: * Indicates Female Test Subject Response

Sound file **"B"**: British male voice (am1s03b2c4) with the words: *"He carried a bag of tennis balls. The scheme was plotted out."*

Table 18. Trial 1 Sound File "C" Raw Data

SOUND FILE "C"	SURVEY QUESTIONS									
	SF_CQ_1	SF_CQ_2	SF_CQ_3	SF_CQ_4	SF_CQ_5	SF_CQ_6	SF_CQ_7	SF_CQ_8	SF_CQ_9	SF_CQ_{10}
Trial 1-1	3	3	0	2	2	3	4	2	3	3
Trial 1-2	2	3	3	1	2	3	3	2	3	3
Trial 1-3	3	3	3	3	3	3	0	2	4	4
Trial 1-4	4	3	3	3	2	3	4	3	4	4
Trial 1-5	4	3	3	3	2	2	4	2	5	3
Trial 1-6	2	1	1	1	2	1	2	2	2	2
***Trial 1-7**	3	3	3	3	3	3	3	3	4	4
Trial 1-8	1	1	1	2	1	1	1	2	1	1
Trial 1-9	2	1	1	2	1	1	4	2	2	2
***Trial 1-10**	3	3	3	2	3	3	2	2	4	3

Note: * Indicates Female Test Subject Response

Sound file **"C"**: British female voice (af1s01b2c16) with the words: *"You were the perfect Hostess. Are you going to be nice to me?"*

Table 19. Trial 1 Sound File "D" Raw Data

SOUND FILE "D"	SURVEY QUESTIONS									
	SF_DQ_1	SF_DQ_2	SF_DQ_3	SF_DQ_4	SF_DQ_5	SF_DQ_6	SF_DQ_7	SF_DQ_8	SF_DQ_9	SF_DQ_{10}
Trial 1-1	3	3	3	3	3	3	4	2	4	4
Trial 1-2	3	3	3	1	3	3	2	2	3	3
Trial 1-3	2	3	3	0	2	2	4	2	3	3
Trial 1-4	4	3	3	3	3	3	4	3	5	4
Trial 1-5	3	3	3	3	2	2	4	2	5	3
Trial 1-6	2	1	1	1	1	0	3	2	1	1
***Trial 1-7**	3	3	3	3	3	2	0	3	3	3
Trial 1-8	3	3	2	1	3	3	0	3	4	4
Trial 1-9	3	3	3	3	2	2	4	2	3	2
***Trial 1-10**	3	3	3	1	2	3	2	2	3	3

Note: * Indicates Female Test Subject Response

Sound file **"D"**: British male voice (am1s02b2c4) with the words: *"There wasn't a scrap of evidence. The jar was full of water."*

Tables 16, 17, 18, and 19 show the results from Trial 1 and the responses from the 40 test subjects who listened to all sound files in the order of: "A, B, C, D".

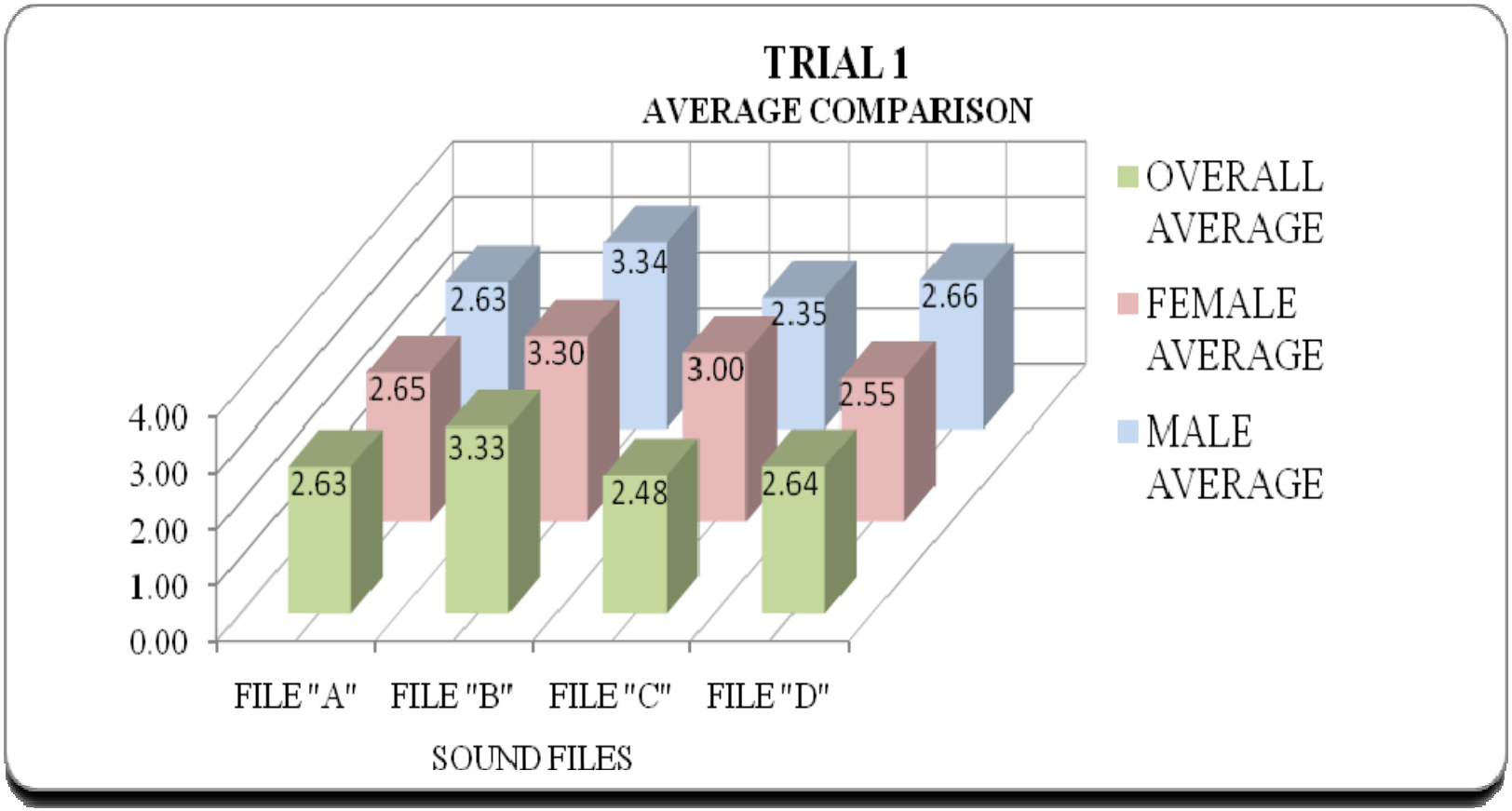

Chart 9. Trial 1 Sound File Comparison

Chart 9 shows the responses of the test subjects by gender.

Table 20. Trial 2 Sound File "B" Raw Data

SOUND FILE "B"	SURVEY QUESTIONS									
	SF_BQ_1	SF_BQ_2	SF_BQ_3	SF_BQ_4	SF_BQ_5	SF_BQ_6	SF_BQ_7	SF_BQ_8	SF_BQ_9	SF_BQ_{10}
Trial 2-1	3	3	3	3	4	4	4	2	4	5
Trial 2-2	2	3	3	1	3	3	3	2	3	4
***Trial 2-3**	3	3	3	3	3	3	3	3	3	3
Trial 2-4	3	3	3	3	2	3	4	2	4	4
Trial 2-5	3	3	3	3	3	3	4	3	4	4
Trial 2-6	3	3	3	2	4	3	3	2	4	4
***Trial 2-7**	4	3	3	3	4	3	4	2	5	4
Trial 2-8	4	3	3	3	4	4	4	2	5	5
Trial 2-9	4	3	3	3	4	4	4	2	5	5
Trial 2-10	3	3	3	3	3	3	3	2	4	3

Note: * Indicates Female Test Subject Response

Sound file **"B"**: British male voice (am1s03b2c4) with the words: *"He carried a bag of tennis balls. The scheme was plotted out."*

Table 21. Trial 2 Sound File "C" Raw Data

SOUND FILE "C"	SURVEY QUESTIONS									
	SF_CQ_1	SF_CQ_2	SF_CQ_3	SF_CQ_4	SF_CQ_5	SF_CQ_6	SF_CQ_7	SF_CQ_8	SF_CQ_9	SF_CQ_{10}
Trial 2-1	3	3	3	1	3	3	4	2	3	3
Trial 2-2	2	1	1	1	2	2	2	2	3	3
***Trial 2-3**	4	3	3	3	3	2	4	3	4	4
Trial 2-4	3	3	3	3	2	3	4	2	4	4
Trial 2-5	2	3	3	1	2	2	4	3	3	3
Trial 2-6	3	3	3	3	1	2	4	2	4	2
***Trial 2-7**	4	3	3	3	2	2	4	2	5	4
Trial 2-8	4	3	3	3	2	2	4	2	4	3
Trial 2-9	4	3	3	3	2	3	4	2	4	4
Trial 2-10	2	3	1	1	3	3	2	2	2	3

Note: * Indicates Female Test Subject Response

Sound file **"C"**: British female voice (af1s01b2c16) with the words: *"You were the perfect Hostess. Are you going to be nice to me?"*

Table 22. Trial 2 Sound File "D" Raw Data

SOUND FILE "D"	SURVEY QUESTIONS									
	SF_DQ_1	SF_DQ_2	SF_DQ_3	SF_DQ_4	SF_DQ_5	SF_DQ_6	SF_DQ_7	SF_DQ_8	SF_DQ_9	SF_DQ_{10}
Trial 2-1	3	3	3	1	2	3	4	2	3	3
Trial 2-2	4	3	3	3	4	4	4	2	5	5
***Trial 2-3**	4	3	3	3	4	3	4	4	5	5
Trial 2-4	4	3	3	3	2	3	4	2	5	4
Trial 2-5	4	3	3	3	4	4	4	3	4	4
Trial 2-6	3	3	3	2	1	2	3	2	3	2
***Trial 2-7**	4	3	3	3	3	3	4	2	4	4
Trial 2-8	4	3	3	3	4	4	4	2	5	4
Trial 2-9	4	3	3	3	4	4	4	2	5	5
Trial 2-10	2	1	1	2	2	2	0	2	2	2

Note: * Indicates Female Test Subject Response

Sound file **"D"**: British male voice (am1s02b2c4) with the words: *"There wasn't a scrap of evidence. The jar was full of water."*

Table 23. Trial 2 Sound File "A" Raw Data

SOUND FILE "A"	SURVEY QUESTIONS									
	SF_AQ_1	SF_AQ_2	SF_AQ_3	SF_AQ_4	SF_AQ_5	SF_AQ_6	SF_AQ_7	SF_AQ_8	SF_AQ_9	SF_AQ_{10}
Trial 2-1	3	3	3	1	2	3	4	2	3	2
Trial 2-2	3	3	3	3	4	4	3	2	4	4
***Trial 2-3**	4	3	3	3	4	4	4	4	5	5
Trial 2-4	4	3	3	3	4	4	4	2	4	4
Trial 2-5	3	3	3	1	2	3	4	3	3	3
Trial 2-6	4	3	1	1	1	1	2	2	2	1
***Trial 2-7**	3	3	1	1	2	2	4	2	3	2
Trial 2-8	4	3	3	3	3	3	4	2	5	4
Trial 2-9	3	3	3	3	4	4	2	2	4	5
Trial 2-10	2	3	1	1	3	3	3	2	2	3

Note: * Indicates Female Test Subject Response

Sound file **"A"**: British female voice (af1s03b2c17) with the words: *"He took out his pipe and lit up. It was a separate bar."*

Tables 20, 21, 22 and 23 show the results of Trial 2 and the responses from the 40 test subjects who listened to all sound files in the order of "B, C, D, A".

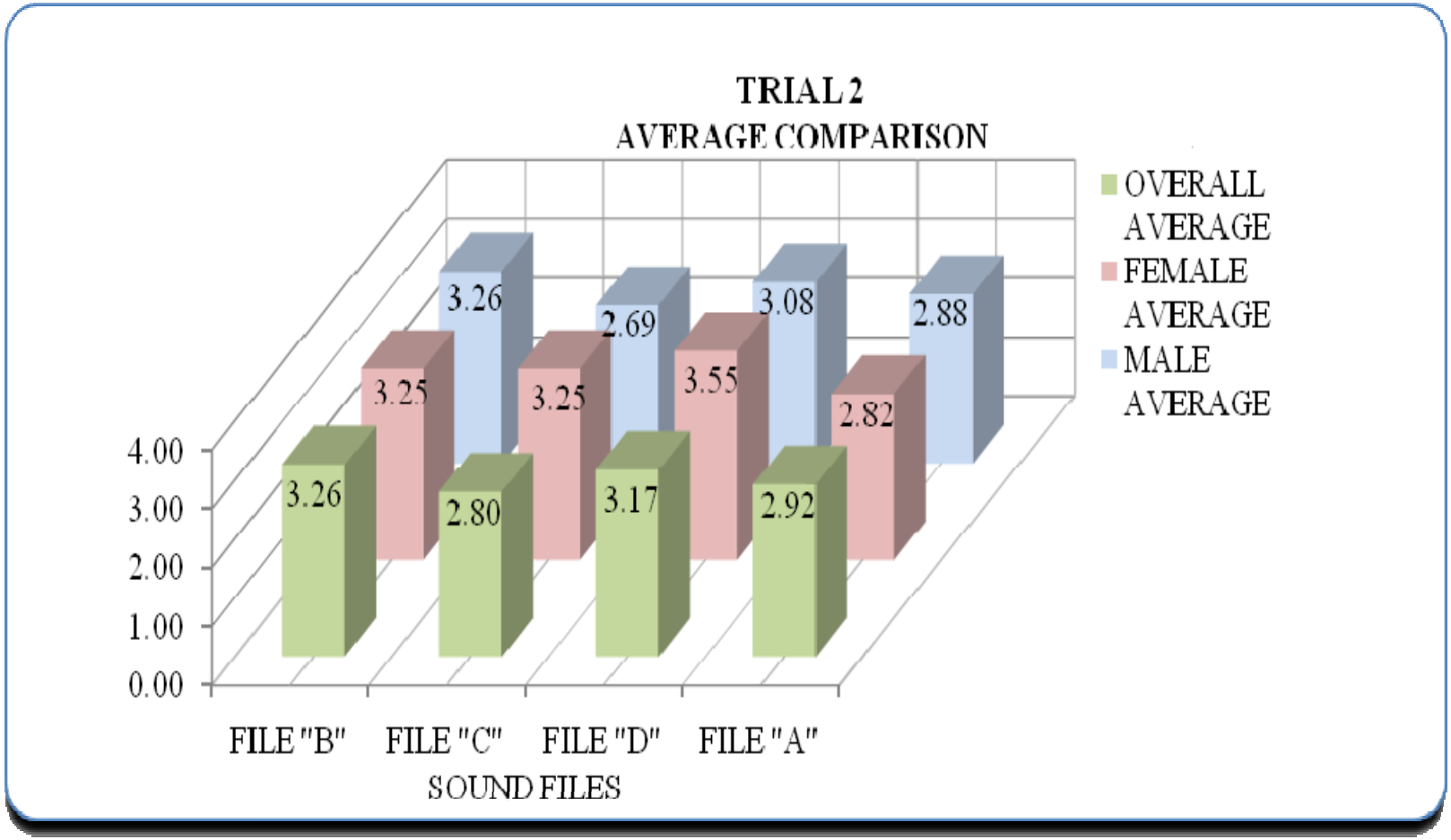

Chart 10. Trial 2 Sound File Comparison

Chart 10 shows the responses of the test subjects by gender:

Table 24. Trial 3 Sound File "C" Raw Data

SOUND FILE "C"	SURVEY QUESTIONS									
	SF_CQ_1	SF_CQ_2	SF_CQ_3	SF_CQ_4	SF_CQ_5	SF_CQ_6	SF_CQ_7	SF_CQ_8	SF_CQ_9	SF_CQ_{10}
Trial 3-1	3	3	3	3	3	3	4	2	4	4
Trial 3-2	2	1	1	2	1	3	0	2	3	3
Trial 3-3	3	3	3	3	3	2	4	2	4	4
Trial 3-4	3	3	3	3	1	2	4	2	4	2
***Trial 3-5**	2	1	3	1	2	2	4	3	3	2
***Trial 3-6**	3	3	3	1	3	3	4	4	4	3
Trial 3-7	3	3	3	1	2	2	4	2	4	3
***Trial 3-8**	2	3	2	2	2	3	2	2	3	4
***Trial 3-9**	3	1	3	3	2	3	0	2	4	3
Trial 3-10	3	3	3	3	2	2	3	3	4	3

Note: * Indicates Female Test Subject Responses

Sound file **"C"**: British female voice (af1s01b2c16) with the words: *"You were the perfect Hostess. Are you going to be nice to me?"*

Table 25. Trial 3 Sound File "D" Raw Data

SOUND FILE "D"	SURVEY QUESTIONS									
	SF_DQ_1	SF_DQ_2	SF_DQ_3	SF_DQ_4	SF_DQ_5	SF_DQ_6	SF_DQ_7	SF_DQ_8	SF_DQ_9	SF_DQ_{10}
Trial 3-1	3	3	3	1	2	2	4	2	3	2
Trial 3-2	2	1	3	1	2	3	1	2	3	2
Trial 3-3	4	3	3	3	4	4	4	2	5	5
Trial 3-4	2	3	3	1	1	2	1	2	3	2
***Trial 3-5**	3	3	3	3	4	3	4	4	4	4
***Trial 3-6**	2	3	3	1	3	3	2	4	3	3
Trial 3-7	3	3	3	3	3	2	4	2	4	3
***Trial 3-8**	2	1	2	1	2	2	4	3	2	3
***Trial 3-9**	3	1	3	1	2	3	0	2	4	3
Trial 3-10	3	3	3	3	4	3	4	3	4	4

Note: * Indicates Female Test Subject Responses

Sound file **"D"**: British male voice (am1s02b2c4) with the words: *"There wasn't a scrap of evidence. The jar was full of water."*

Table 26. Trial 3 Sound File "A" Raw Data

SOUND FILE "A"	SURVEY QUESTIONS									
	SF_AQ_1	SF_AQ_2	SF_AQ_3	SF_AQ_4	SF_AQ_5	SF_AQ_6	SF_AQ_7	SF_AQ_8	SF_AQ_9	SF_AQ_{10}
Trial 3-1	3	3	3	1	3	3	4	2	3	3
Trial 3-2	2	1	1	1	2	3	1	2	3	3
Trial 3-3	3	3	3	1	3	3	4	2	4	4
Trial 3-4	2	3	1	1	2	2	1	2	2	2
***Trial 3-5**	3	3	3	3	4	3	4	4	4	4
***Trial 3-6**	3	3	3	3	4	4	1	3	3	4
Trial 3-7	3	3	3	1	2	2	4	2	4	3
***Trial 3-8**	3	3	3	1	2	3	2	3	4	4
***Trial 3-9**	3	1	3	0	1	2	3	2	3	2
Trial 3-10	2	3	3	3	3	3	3	3	3	4

Note: * Indicates Female Test Subject Responses

Sound file **"A"**: British female voice (af1s03b2c17) with the words: *"He took out his pipe and lit up. It was a separate bar."*

Table 27. Trial 3 Sound File "B" Raw Data

SOUND FILE "B"	SURVEY QUESTIONS									
	SF_BQ_1	SF_BQ_2	SF_BQ_3	SF_BQ_4	SF_BQ_5	SF_BQ_6	SF_BQ_7	SF_BQ_8	SF_BQ_9	SF_BQ_{10}
Trial 3-1	3	3	3	3	4	3	4	2	5	4
Trial 3-2	3	1	1	1	2	3	1	2	3	3
Trial 3-3	4	3	3	3	4	4	4	2	5	5
Trial 3-4	3	3	3	3	3	3	4	2	4	3
***Trial 3-5**	4	3	3	3	4	3	4	4	4	4
***Trial 3-6**	4	3	3	3	4	4	2	3	5	5
Trial 3-7	4	3	3	3	4	3	4	2	5	4
***Trial 3-8**	3	3	3	2	2	3	3	3	4	4
***Trial 3-9**	4	3	3	3	4	4	4	2	5	4
Trial 3-10	3	3	3	3	4	3	3	3	4	4

Note: * Indicates Female Test Subject Responses

Sound file **"B"**: British male voice (am1s03b2c4) with the words: *"He carried a bag of tennis balls. The scheme was plotted out."*

Tables 24, 25, 26 and 27 show the results of Trial 3 and the responses from the 40 test subjects who listened to all sound files in the order of "C, D, A, B

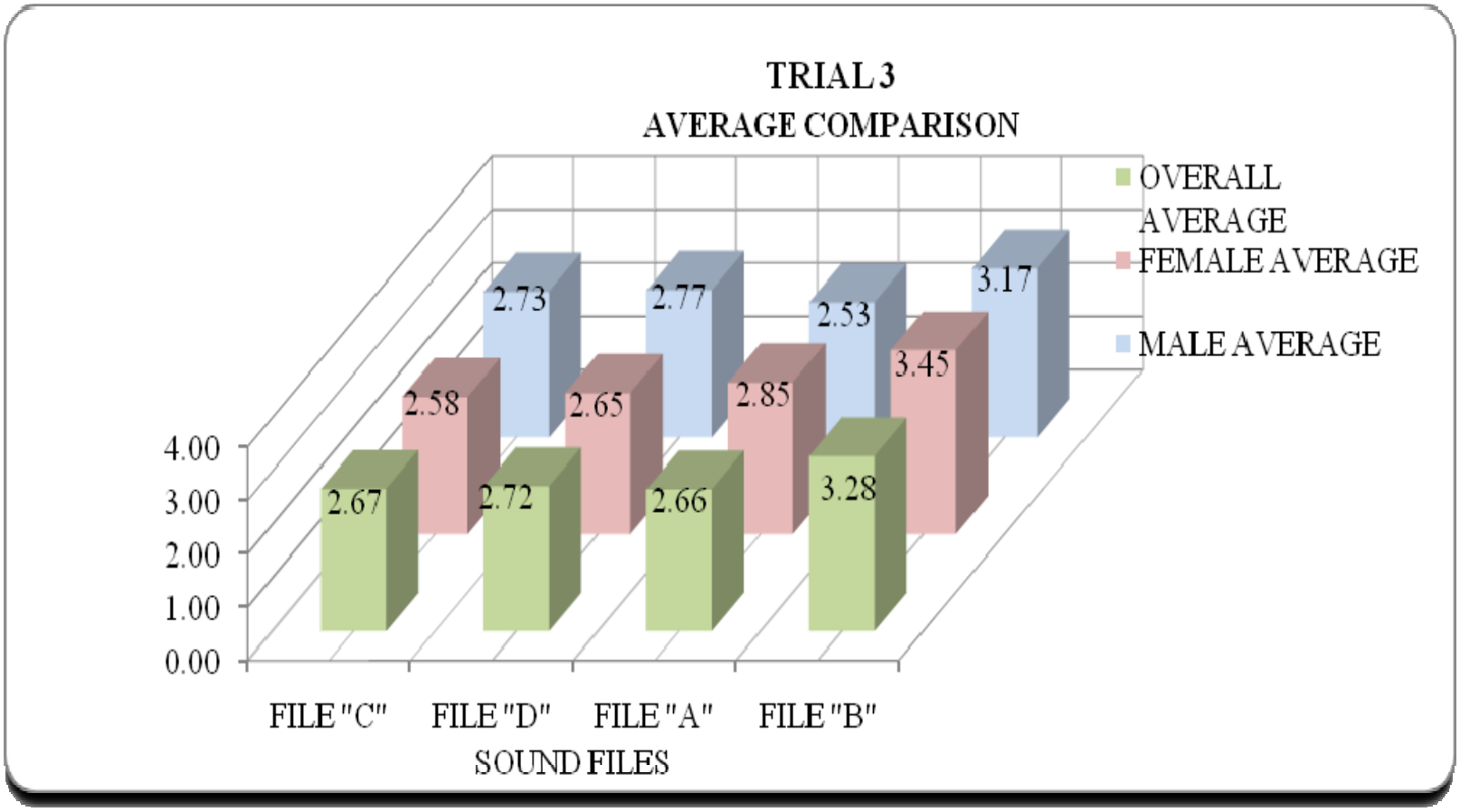

Chart 11. Trial 3 Sound File Comparison

Chart 11 shows the responses of the test subjects by gender.

Table 28. Trial 4 Sound File "D" Raw Data

SOUND FILE "D"	SURVEY QUESTIONS									
	SF_DQ_1	SF_DQ_2	SF_DQ_3	SF_DQ_4	SF_DQ_5	SF_DQ_6	SF_DQ_7	SF_DQ_8	SF_DQ_9	SF_DQ_{10}
***Trial 4-1**	3	3	1	1	2	2	4	2	3	2
***Trial 4-2**	2	1	0	1	2	3	2	0	3	3
Trial 4-3	3	1	2	3	2	3	0	2	3	2
Trial 4-4	3	3	3	1	2	3	2	2	4	3
***Trial 4-5**	2	3	3	3	1	1	4	3	3	2
Trial 4-6	3	1	2	3	1	3	0	2	3	2
Trial 4-7	4	3	3	1	2	2	4	3	5	3
***Trial 4-8**	4	3	3	3	1	1	0	3	5	2
***Trial 4-9**	3	3	3	3	2	2	4	2	4	4
Trial 4-10	3	3	3	3	2	3	4	3	4	3

Note: * Indicates Female Test Subject Responses

Sound file **"D"**: British male voice (am1s02b2c4) with the words: *"There wasn't a scrap of evidence. The jar was full of water."*

Table 29. Trial 4 Sound File "A" Raw Data

SOUND FILE "A"	SURVEY QUESTIONS									
	SF_AQ_1	SF_AQ_2	SF_AQ_3	SF_AQ_4	SF_AQ_5	SF_AQ_6	SF_AQ_7	SF_AQ_8	SF_AQ_9	SF_AQ_{10}
***Trial 4-1**	3	3	1	1	2	2	3	2	3	2
***Trial 4-2**	3	3	3	0	4	4	3	0	4	4
Trial 4-3	3	1	3	1	2	3	3	2	2	2
Trial 4-4	3	3	1	4	3	2	2	4	4	
***Trial 4-5**	2	3	3	3	2	2	3	3	3	3
Trial 4-6	2	3	3	1	2	3	3	2	3	2
Trial 4-7	4	3	3	1	2	3	4	3	4	3
***Trial 4-8**	3	3	3	3	1	1	4	3	5	2
***Trial 4-9**	4	3	3	3	2	3	4	2	4	4
Trial 4-10	3	3	3	3	2	3	4	3	4	3

Note: * Indicates Female Test Subject Responses

Sound file **"A"**: British female voice (af1s03b2c17) with the words: *"He took out his pipe and lit up. It was a separate bar."*

Table 30. Trial 4 Sound File "B" Raw Data

SOUND FILE "B"	SURVEY QUESTIONS									
	SF_BQ_1	SF_BQ_2	SF_BQ_3	SF_BQ_4	SF_BQ_5	SF_BQ_6	SF_BQ_7	SF_BQ_8	SF_BQ_9	SF_BQ_{10}
***Trial 4-1**	4	3	3	3	4	3	4	2	4	5
***Trial 4-2**	3	3	3	1	4	3	1	0	4	4
Trial 4-3	3	3	3	3	2	4	3	2	5	5
Trial 4-4	4	3	3	3	4	4	2	2	4	5
***Trial 4-5**	4	3	3	3	4	3	4	3	4	4
Trial 4-6	4	3	3	3	4	4	1	2	5	5
Trial 4-7	4	3	3	3	4	4	4	3	5	5
***Trial 4-8**	4	3	3	3	4	4	4	3	5	5
***Trial 4-9**	4	3	3	3	4	4	4	2	5	5
Trial 4-10	4	3	3	3	4	4	4	3	5	5

Note: * Indicates Female Test Subject Responses

Sound file **"B"**: British male voice (am1s03b2c4) with the words: *"He carried a bag of tennis balls. The scheme was plotted out."*

Table 31. Trial 4 Sound File "C" Raw Data

SOUND FILE "C"	SURVEY QUESTIONS									
	SF_CQ_1	SF_CQ_2	SF_CQ_3	SF_CQ_4	SF_CQ_5	SF_CQ_6	SF_CQ_7	SF_CQ_8	SF_CQ_9	SF_CQ_{10}
***Trial 4-1**	2	3	1	2	2	2	3	2	3	3
***Trial 4-2**	2	1	1	1	2	2	2	0	2	2
Trial 4-3	3	3	3	2	2	2	3	2	3	3
Trial 4-4	2	1	1	1	2	3	2	2	3	3
***Trial 4-5**	3	3	3	3	2	2	4	3	4	3
Trial 4-6	3	1	3	1	2	2	2	2	3	2
Trial 4-7	4	3	3	3	3	3	4	3	4	3
***Trial 4-8**	3	3	3	3	2	3	3	3	4	3
***Trial 4-9**	3	3	3	3	3	2	4	2	4	3
Trial 4-10	3	3	3	1	2	3	3	3	4	3

Note: * Indicates Female Test Subject Responses

Sound file **"C"**: British female voice (af1s01b2c16) with the words: *"You were the perfect Hostess. Are you going to be nice to me?"*

Tables 28, 29, 30 and 31 show the results of Trial 3 and the responses from the 40 test subjects who listened to all sound files in the order of "D, A, B, C.

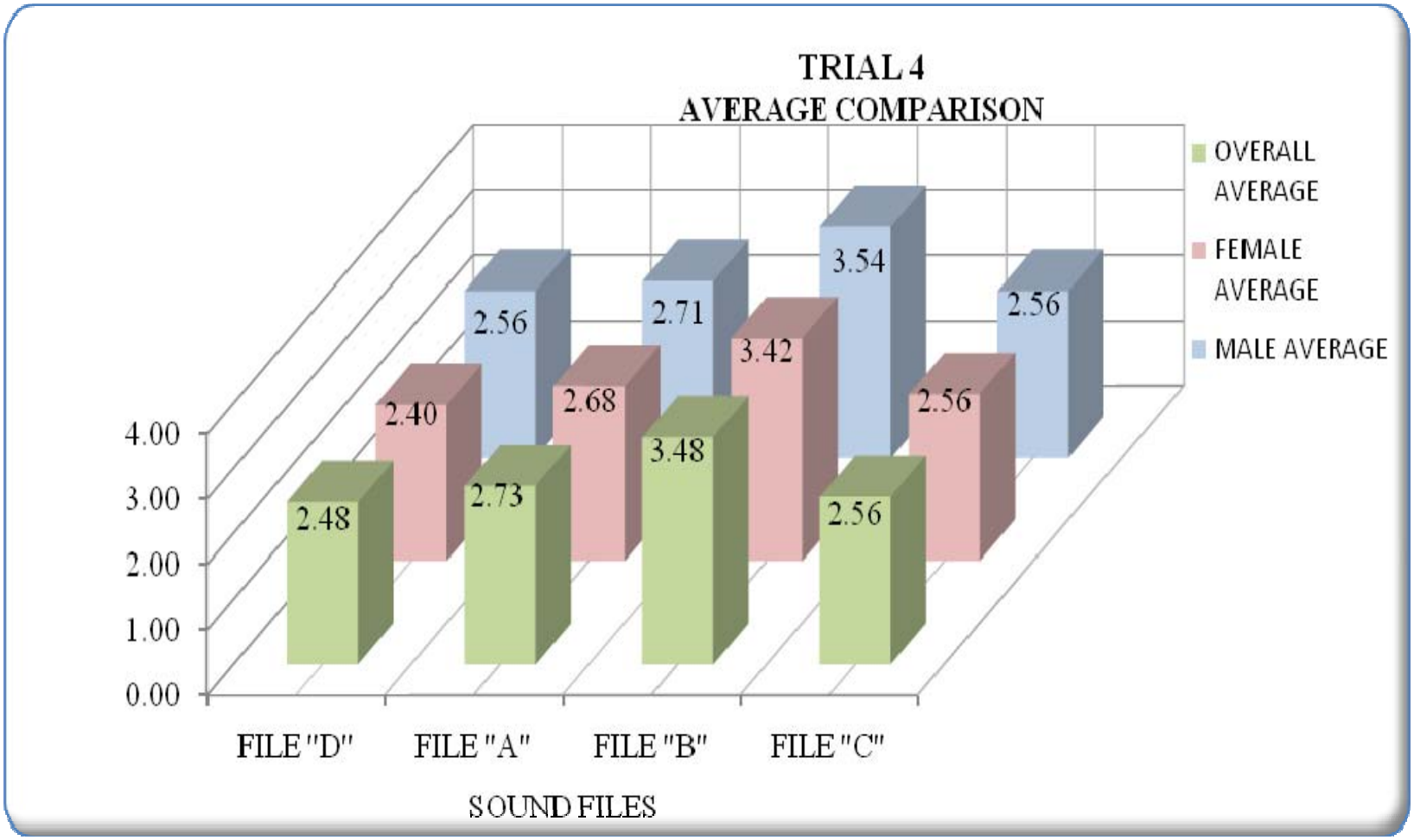

Chart 12. Trial 4 Sound File Comparison

Chart 12 shows the responses of the test subjects by gender

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APPENDIX E MULTI-ATTRIBUTE ANALYSIS

Appendix E shows the comparison of two similar questions which illustrates how the test subjects perceived quality of each of the sound files at the various stations.

Table 32. Question 3 & 4 Raw Data

	STATION ONE		STATION TWO		STATION THREE		STATION FOUR	
Test Subject	S_1Q_3	S_1Q_4	S_2Q_3	S_2Q_4	S_3Q_3	S_3Q_4	S_4Q_3	S_4Q_4
TS-1	1	2	3	2	1	2	3	3
TS-2	3	1	3	3	0	1	3	1
TS-3	2	1	3	3	3	2	3	3
TS-4	3	3	3	3	3	3	3	3
TS-5	3	3	3	3	3	3	3	3
TS-6	1	1	3	3	3	1	3	1
TS-7	3	1	3	2	3	2	1	1
TS-8	1	1	3	3	3	0	1	1
TS-9	3	3	3	3	3	3	3	3
TS-10	3	1	3	1	3	1	3	2
TS-11	3	3	3	0	3	1	3	1
TS-12	3	3	3	3	2	1	3	3
TS-13	1	1	3	3	3	2	3	3
TS-14	3	3	3	3	3	3	3	3
TS-15	2	1	3	3	0	1	3	0
TS-16	3	3	3	3	3	1	3	1
TS-17	2	1	3	3	3	1	3	3
TS-18	1	1	3	3	3	3	3	3
TS-19	3	3	3	3	3	3	2	1
TS-20	2	1	3	3	3	2	3	3

Table 33. Question 3 & 4 Raw Data (cont)

	STATION ONE		STATION TWO		STATION THREE		STATION FOUR	
Test Subject	S_1Q_3	S_1Q_4	S_2Q_3	S_2Q_4	S_3Q_3	S_3Q_4	S_4Q_3	S_4Q_4
TS-21	1	2	3	2	1	3	3	3
TS-22	1	1	3	3	`	1	1	1
TS-23	1	3	3	3	2	1	3	2
TS-24	1	1	3	3	3	3	3	3
TS-25	3	3	3	3	3	3	3	3
TS-26	3	3	3	3	3	1	3	3
TS-27	1	3	3	3	3	2	3	3
TS-28	2	1	3	3	3	3	3	3
TS-29	3	1	3	3	3	1	3	1
TS-30	3	3	3	3	3	3	3	3
TS-31	3	1	3	3	3	3	3	3
TS-32	3	1	3	3	3	3	3	1
TS-33	2	1	3	3	3	1	3	2
TS-34	0	1	3	3	3	2	1	1
TS-35	3	3	3	3	3	3	3	3
TS-36	3	3	3	3	3	3	3	3
TS-37	3	1	3	1	3	2	3	1
TS-38	3	3	3	3	3	3	3	2
TS-39	3	1	3	3	0	1	0	1
TS-40	1	2	3	3	1	1	1	1

Table 34. Question 3 & 4 Raw Data (cont)

	STATION ONE		STATION TWO		STATION THREE		STATION FOUR	
Test Subject	S_1Q_3	S_1Q_4	S_2Q_3	S_2Q_4	S_3Q_3	S_3Q_4	S_4Q_3	S_4Q_4
TS-41	3	3	3	3	3	3	1	1
TS-42	3	3	3	3	1	1	3	3
TS-43	3	1	1	1	3	2	3	2
TS-44	1	1	3	3	3	2	3	1
TS-45	3	3	3	3	1	1	3	2
TS-46	3	1	3	3	1	2	3	3
TS-47	3	1	3	3	3	3	3	3
TS-48	3	3	3	3	3	3	3	3
TS-49	3	3	3	3	3	3	3	3
TS-50	1	1	3	3	1	2	2	3
TS-51	3	3	3	3	3	2	3	1
TS-52	1	1	3	3	1	1	1	2
TS-53	3	3	3	3	3	3	3	3
TS-54	3	3	3	3	3	1	3	3
TS-55	1	1	3	2	3	2	3	2
TS-56	3	3	3	3	3	3	3	3
TS-57	3	3	3	3	3	3	1	1
TS-58	2	1	3	3	3	2	3	1
TS-59	3	3	3	3	3	1	3	3
TS-60	1	1	3	3	1	2	3	2
TS-61	2	1	3	3	1	1	2	1

Tables 32, 33 and 34 show the responses from the 61 test subjects at each Station for questions 3 and 4.

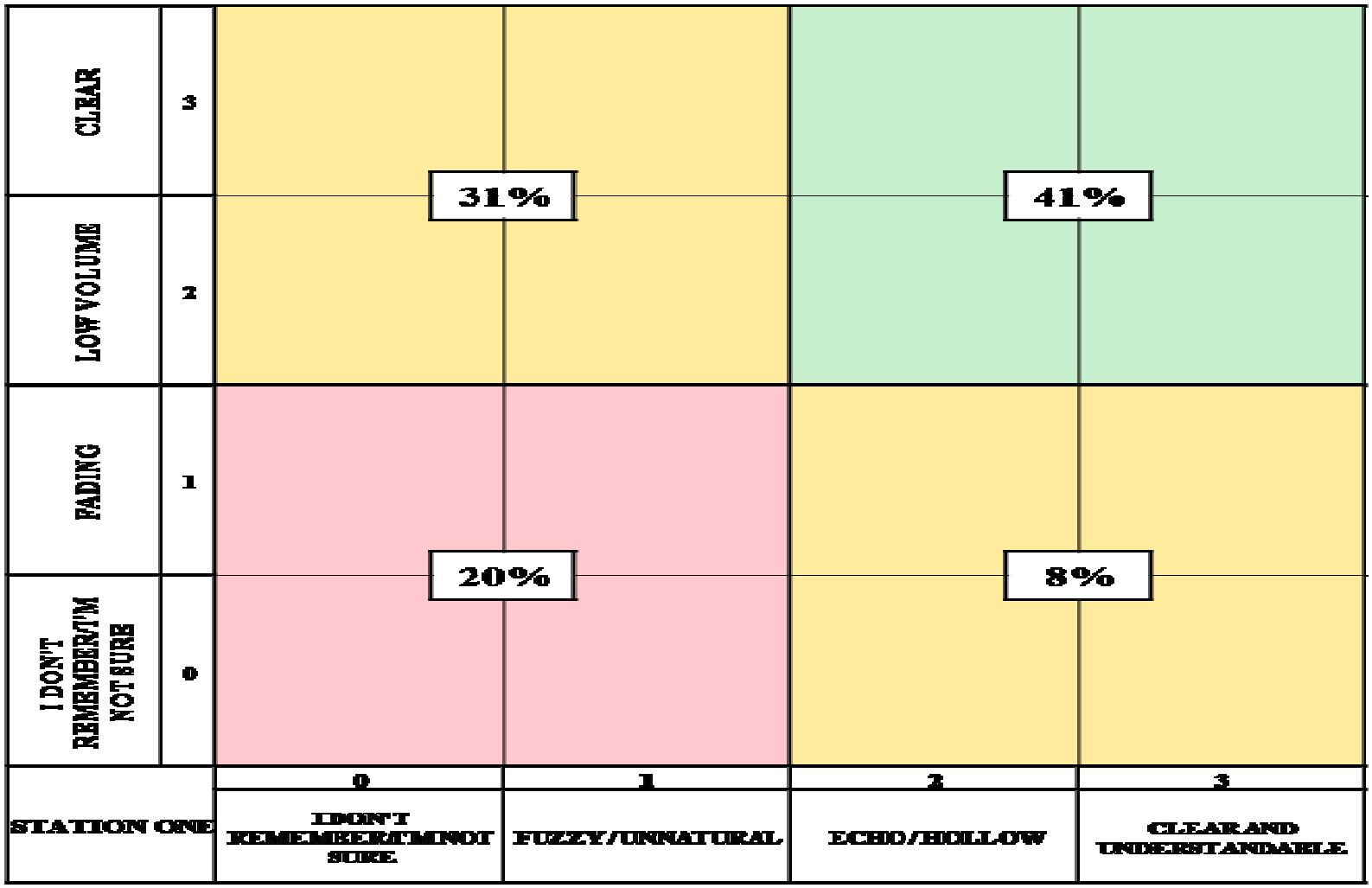

Figure 10. Questions 3 & 4 Station One

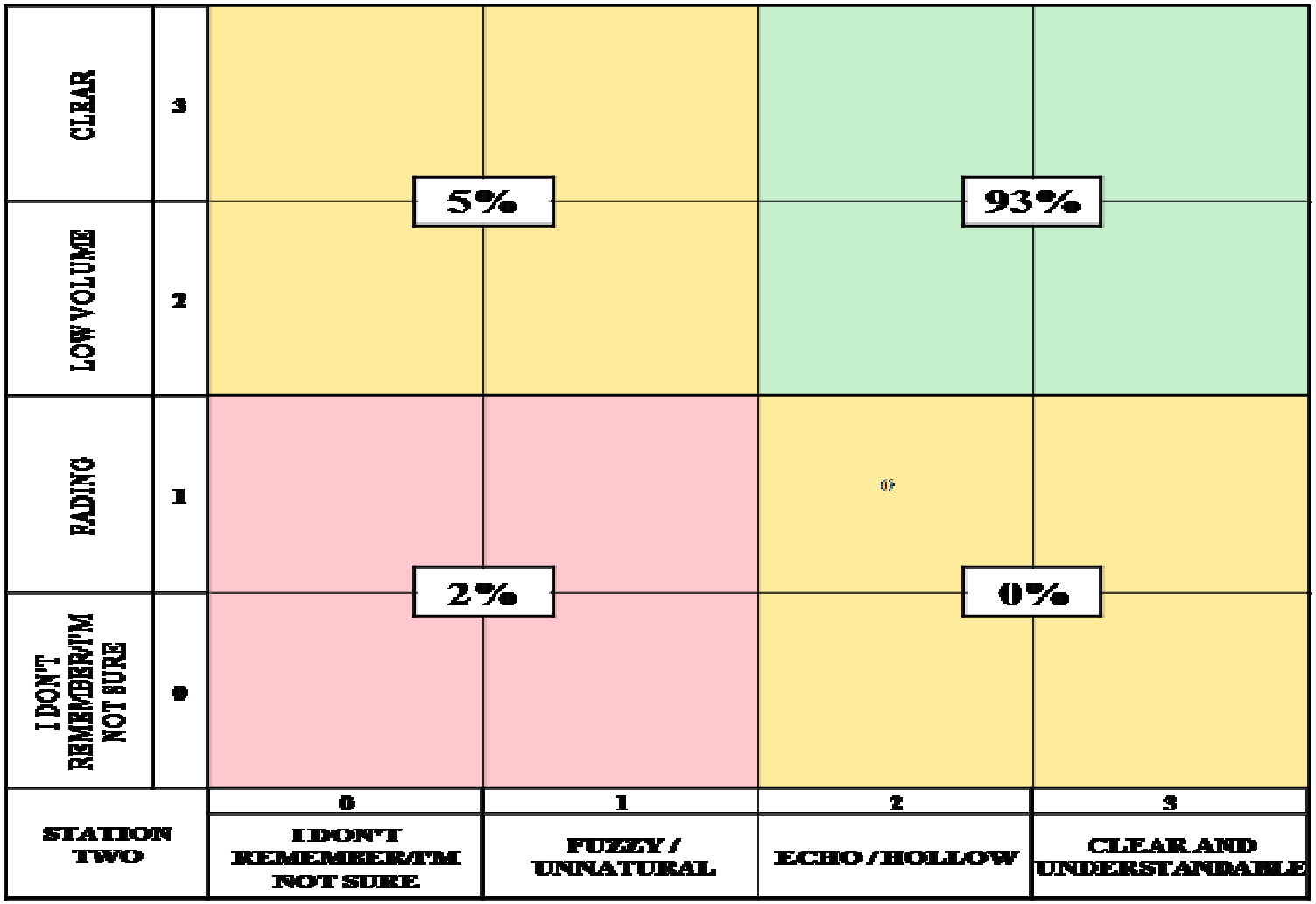

Figure 11. Questions 3 & 4 Station Two

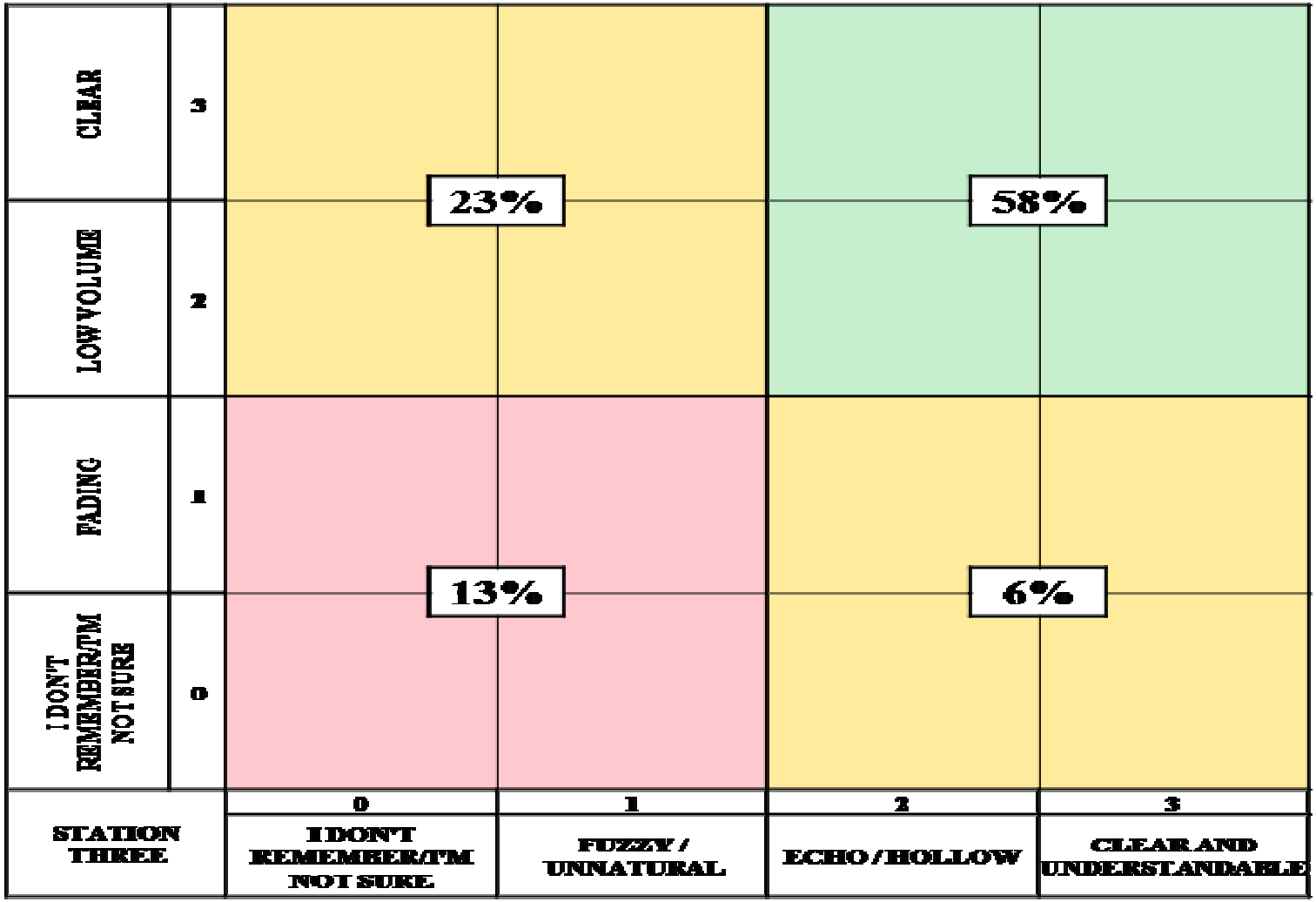

Figure 12. Questions 3 & 4 Station Three

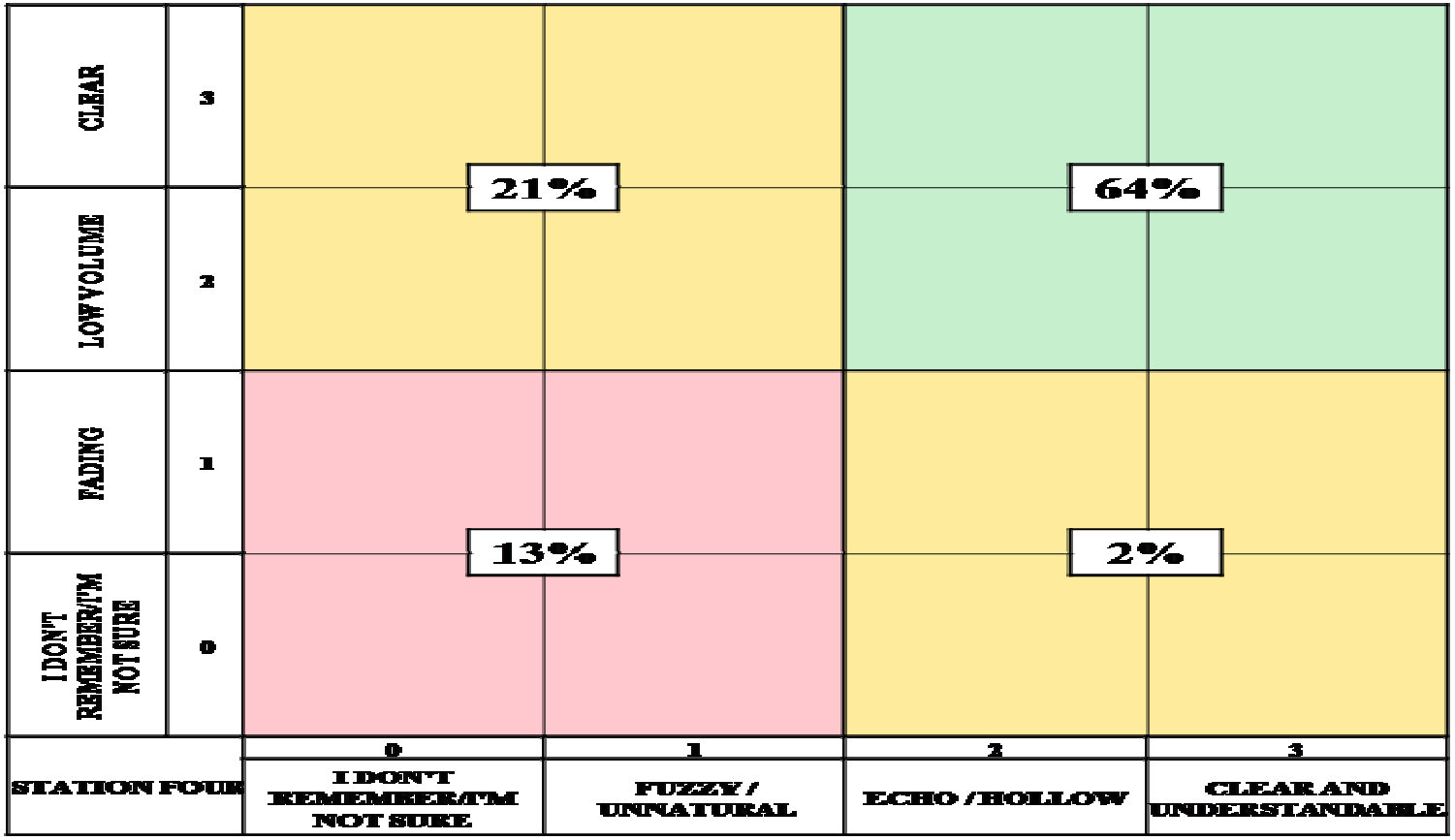

Figure 13. Questions 3 & 4 Station Four

Figures 10, 11, 12 and 13 show the percentage of responses from the 61 test subjects within each quadrant.

Table 35. Questions 9 & 1 Raw Data

	STATION ONE		STATION TWO		STATION THREE		STATION FOUR	
Test Subject	S_1Q_9	S_1Q_1	S_2Q_9	S_2Q_1	S_3Q_9	S_3Q_1	S_4Q_9	S_4Q_1
TS-1	3	2	4	3	2	2	5	3
TS-2	3	2	4	4	2	2	4	3
TS-3	2	1	4	3	4	2	4	3
TS-4	5	4	5	4	5	3	3	4
TS-5	5	4	5	4	5	4	5	4
TS-6	3	1	5	4	5	2	5	3
TS-7	3	2	3	2	2	2	1	1
TS-8	3	3	4	4	4	4	3	3
TS-9	5	4	5	4	4	3	4	3
TS-10	3	2	4	3	4	3	4	3
TS-11	4	3	4	3	3	2	3	2
TS-12	4	4	5	4	3	2	5	4
TS-13	3	1	4	4	3	2	5	4
TS 14	4	3	4	4	5	4	5	4
TS-15	2	1	4	3	3	2	3	3
TS-16	4	3	4	4	2	2	2	2
TS-17	3	2	4	4	4	3	4	3
TS-18	2	2	5	4	5	4	4	3
TS-19	5	4	5	4	4	3	2	1
TS 20	3	2	5	4	3	3	4	4

Table 36. Questions 9 & 1 Raw Data (cont)

	STATION ONE		STATION TWO		STATION THREE		STATION FOUR	
Test Subject	S_1Q_9	S_1Q_1	S_2Q_9	S_2Q_1	S_3Q_9	S_3Q_1	S_4Q_9	S_4Q_1
TS-21	3	2	4	3	4	3	4	3
TS-22	4	2	5	4	3	2	3	2
TS-23	4	3	5	4	3	2	4	3
TS-24	4	3	5	4	5	4	4	3
TS-25	4	3	5	3	5	3	5	4
TS-26	4	3	4	4	3	2	4	3
TS-27	3	2	5	4	4	3	5	4
TS-28	2	2	4	3	4	3	4	3
TS-29	4	4	4	3	3	3	4	3
TS-30	4	4	4	4	5	4	5	4
TS-31	3	3	3	3	4	4	4	3
TS-32	3	2	5	4	4	3	4	3
TS-33	4	3	5	4	4	3	3	2
TS-34	2	2	4	3	4	3	3	2
TS-35	5	4	5	4	5	4	5	4
TS-36	4	3	5	4	3	3	4	3
TS-37	3	2	3	3	3	2	2	1
TS-38	5	4	5	4	5	4	5	4
TS-39	3	3	4	3	3	2	3	2
TS-40	4	3	5	4	3	3	2	2

Table 37. Questions 9 & 1 Raw Data (cont)

	STATION ONE		STATION TWO		STATION THREE		STATION FOUR	
Test Subject	S_1Q_9	S_1Q_1	S_2Q_9	S_2Q_1	S_3Q_9	S_3Q_1	S_4Q_9	S_4Q_1
TS-41	4	3	5	4	4	4	2	2
TS-42	5	4	4	3	3	2	4	3
TS-43	3	3	2	1	3	3	1	1
TS-44	3	3	4	3	3	2	2	2
TS-45	4	3	4	3	3	2	3	3
TS-46	3	2	4	4	4	2	5	4
TS-47	4	3	4	4	4	3	4	3
TS-48	5	1	5	4	5	4	4	3
TS-49	4	3	4	3	4	3	4	3
TS-50	3	2	3	3	2	2	3	3
TS-51	5	4	5	4	3	2	3	3
TS-52	3	2	4	3	3	2	3	2
TS-53	3	3	3	3	4	3	4	3
TS-54	5	4	5	4	4	3	4	3
TS-55	3	2	4	3	4	3	4	3
TS-56	4	3	4	4	5	4	4	3
TS-57	4	4	4	3	4	3	1	1
TS-58	4	3	5	4	4	4	4	3
TS-59	4	2	5	4	4	3	5	4
TS-60	2	2	4	3	3	2	3	2
TS-61	3	2	4	3	2	2	2	2

Tables 35, 36and 37 show the responses from the 61 test subjects at each Station for questions 9 and 1.

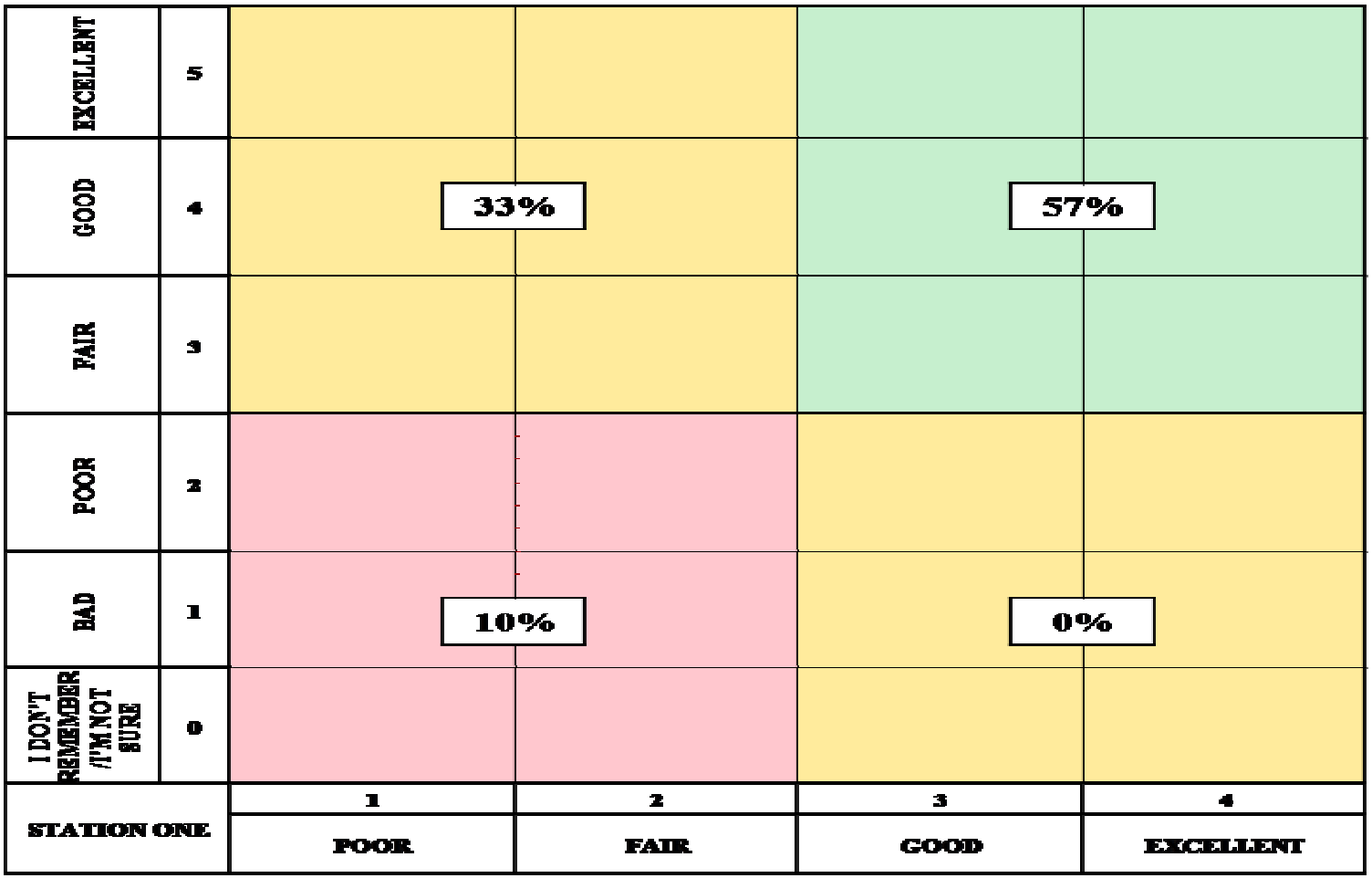

Figure 14. Questions 9 & 1 Station One

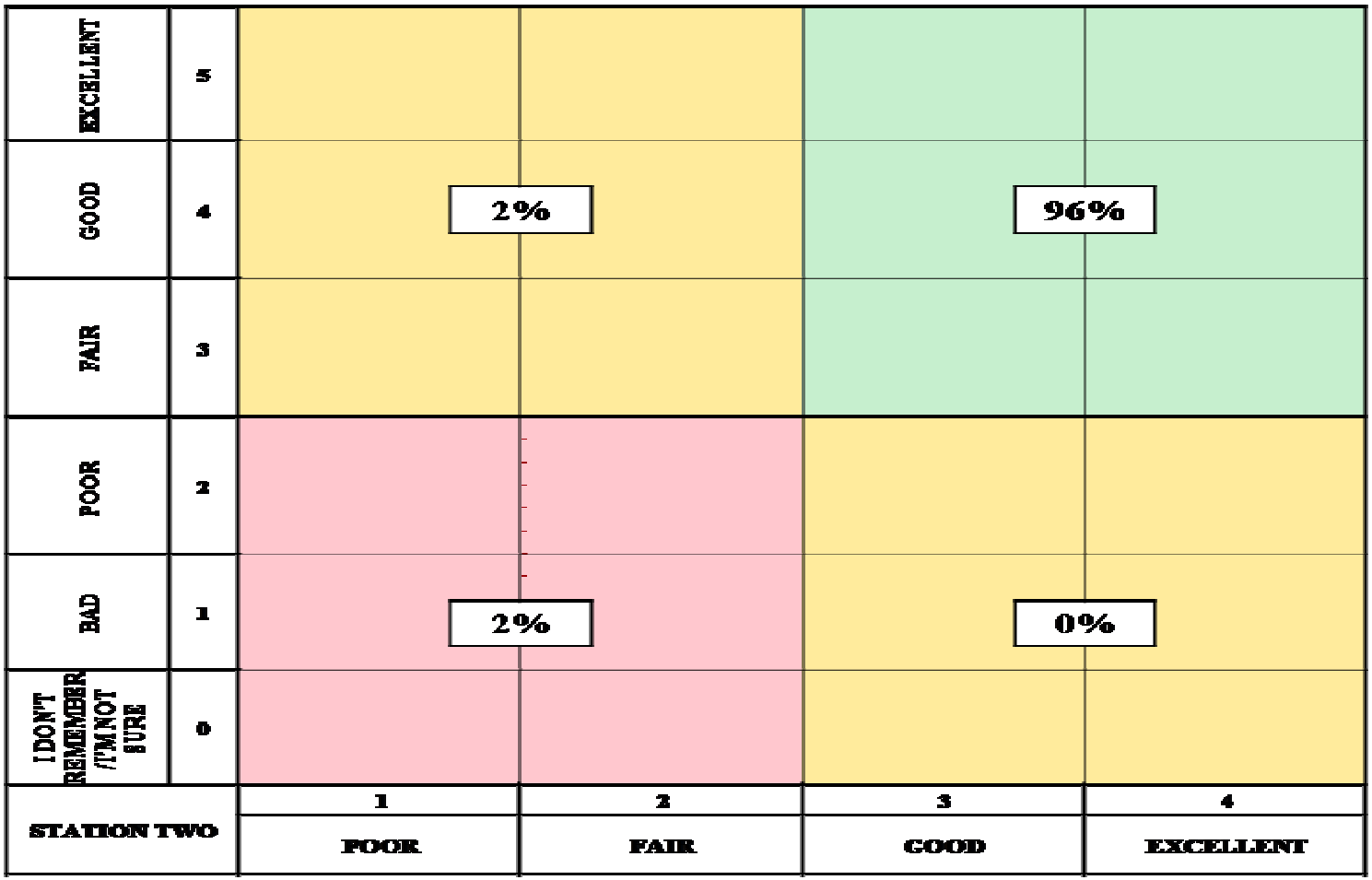

Figure 15. Questions 9 & 1 Station Two

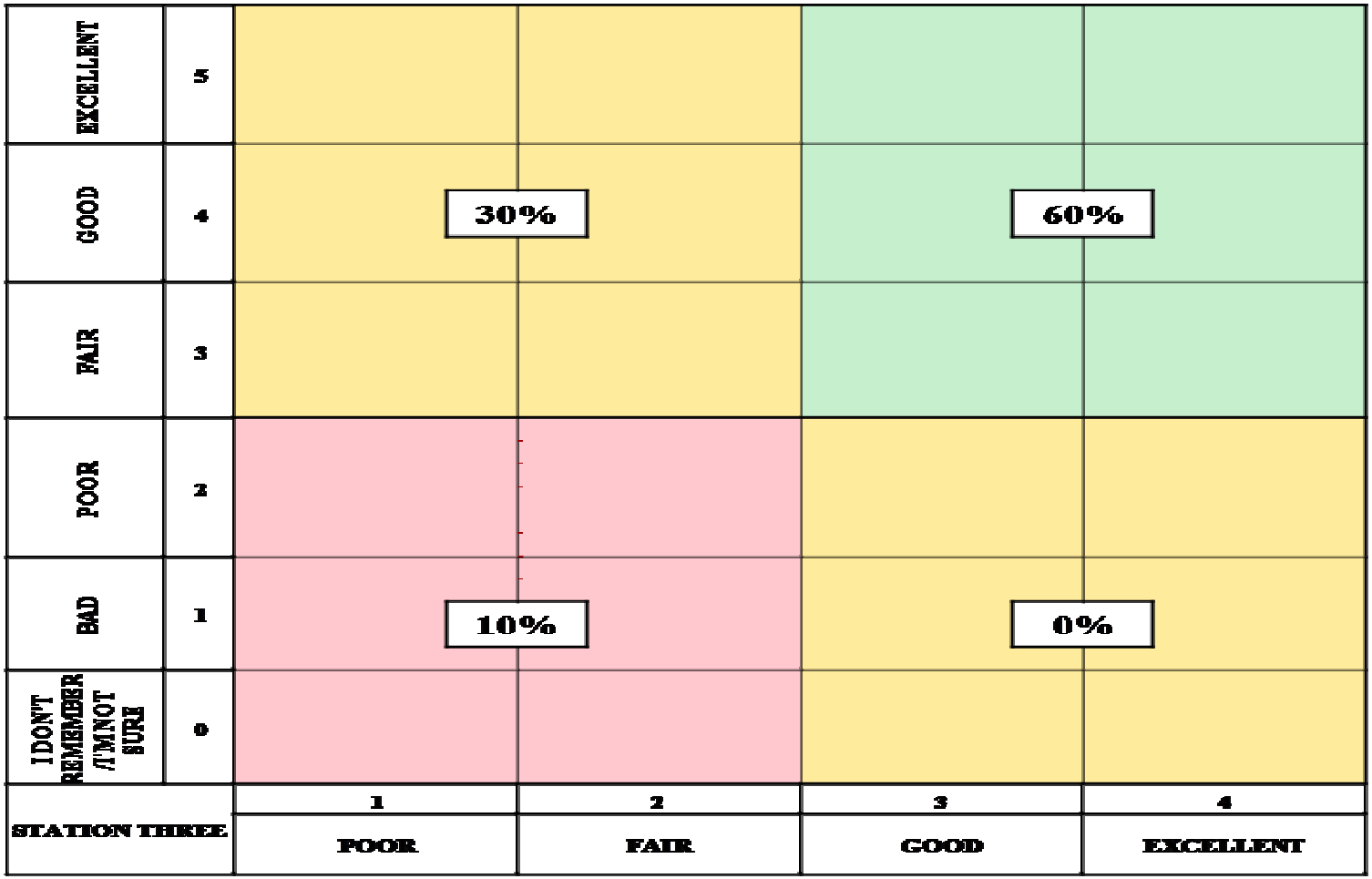

Figure 16. Questions 9 & 1 Station Three

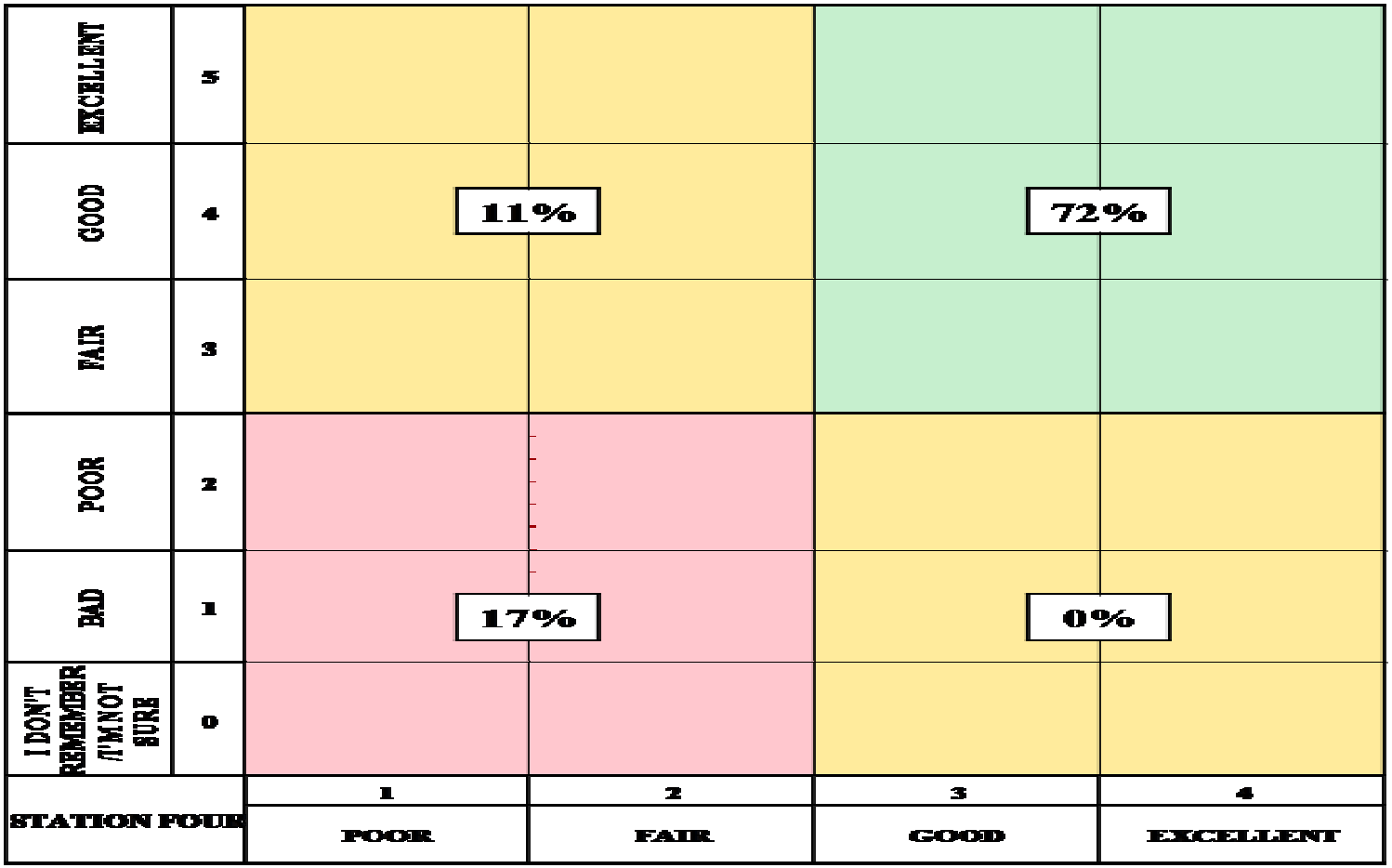

Figure 17. Questions 9 & 1 Station Four

Figures 14, 15, 16 and 17 show the percentage of responses from the 61 test subjects within each quadrant.

Table 38. Questions 10 & 5 Raw Data

	STATION ONE		STATION TWO		STATION THREE		STATION FOUR	
TEST SUBJECTS	S_1Q_{10}	S_1Q_5	S_2Q_{10}	S_2Q_5	S_3Q_{10}	S_3Q_5	S_4Q_{10}	S_4Q_5
TS-1	4	2	4	3	2	2	4	4
TS-2	2	2	5	4	2	2	3	3
TS-3	1	1	3	3	4	1	4	3
TS-4	2	2	5	4	2	2	3	2
TS-5	1	1	4	4	4	4	4	3
TS-6	2	1	5	4	3	2	3	3
TS-7	3	2	4	3	3	2	1	1
TS-8	3	2	4	4	4	2	3	2
TS-9	4	3	4	3	4	2	4	3
TS-10	3	2	4	4	3	2	3	3
TS-11	4	3	4	4	3	2	2	2
TS-12	4	3	5	4	3	2	5	3
TS-13	1	1	5	4	3	2	5	4
TS-14	4	2	4	3	4	3	4	3
TS-15	1	1	4	2	2	1	3	3
TS-16	3	2	3	2	1	1	1	1
TS-17	3	2	4	3	3	2	4	3
TS-18	2	1	3	4	4	3	2	2
TS-19	5	2	5	4	4	2	2	1
TS-20	3	2	4	2	3	2	4	2

Table 39. Questions 10 & 5 Raw Data (cont)

	STATION ONE		STATION TWO		STATION THREE		STATION FOUR	
TEST SUBJECTS	S_1Q_{10}	S_1Q_5	S_2Q_{10}	S_2Q_5	S_3Q_{10}	S_3Q_5	S_4Q_{10}	S_4Q_5
TS-21	2	2	4	2	3	2	4	2
TS-22	3	2	5	4	3	2	2	2
TS-23	3	2	5	4	4	3	3	2
TS-24	3	2	5	4	5	4	4	3
TS-25	3	2	4	3	4	3	5	4
TS-26	3	3	4	4	3	2	4	3
TS-27	4	4	5	4	4	4	4	4
TS-28	2	1	4	4	4	4	3	3
TS-29	4	3	4	3	3	2	3	2
TS-30	4	2	5	4	4	2	5	4
TS-31	3	2	3	2	4	4	4	3
TS-32	4	4	5	4	5	4	5	4
TS-33	4	4	4	3	3	3	3	2
TS-34	2	2	4	3	2	2	3	2
TS-35	4	3	5	4	5	4	5	4
TS-36	4	2	4	4	3	2	4	3
TS-37	3	2	3	3	3	2	2	1
TS-38	5	4	5	4	3	3	5	4
TS-39	3	2	3	2	2	1	3	2
TS-40	3	2	4	4	3	2	2	2

Table 40. Questions 10 & 5 Raw Data (cont.)

	STATION ONE		STATION TWO		STATION THREE		STATION FOUR	
TEST SUBJECTS	S_1Q_{10}	S_1Q_5	S_2Q_{10}	S_2Q_5	S_3Q_{10}	S_3Q_5	S_4Q_{10}	S_4Q_5
TS-41	4	4	5	4	2	2	1	1
TS-42	4	3	4	4	2	2	3	3
TS-43	3	3	2	1	3	2	2	1
TS-44	3	2	4	3	2	2	1	1
TS-45	4	2	5	4	1	1	4	4
TS-46	2	1	4	3	3	2	4	3
TS-47	2	1	4	2	2	1	2	1
TS-48	3	1	5	4	2	1	3	2
TS-49	4	3	5	4	3	4	4	4
TS-50	3	2	3	2	2	1	3	3
TS-51	3	2	5	4	2	1	3	2
TS-52	3	2	4	4	1	1	2	2
TS-53	3	2	4	2	3	2	3	2
TS-54	5	4	5	4	3	2	4	2
TS-55	2	2	3	2	3	2	4	2
TS-56	4	3	4	4	5	4	4	4
TS-57	4	4	4	3	4	3	1	1
TS-58	4	3	5	4	3	2	2	1
TS-59	3	2	5	4	4	3	5	4
TS-60	3	2	4	3	3	2	4	3
TS-61	2	2	4	3	2	1	2	2

Tables 38, 39 and 40 show the responses from the 61 test subjects at each Station for questions 10 and 5.

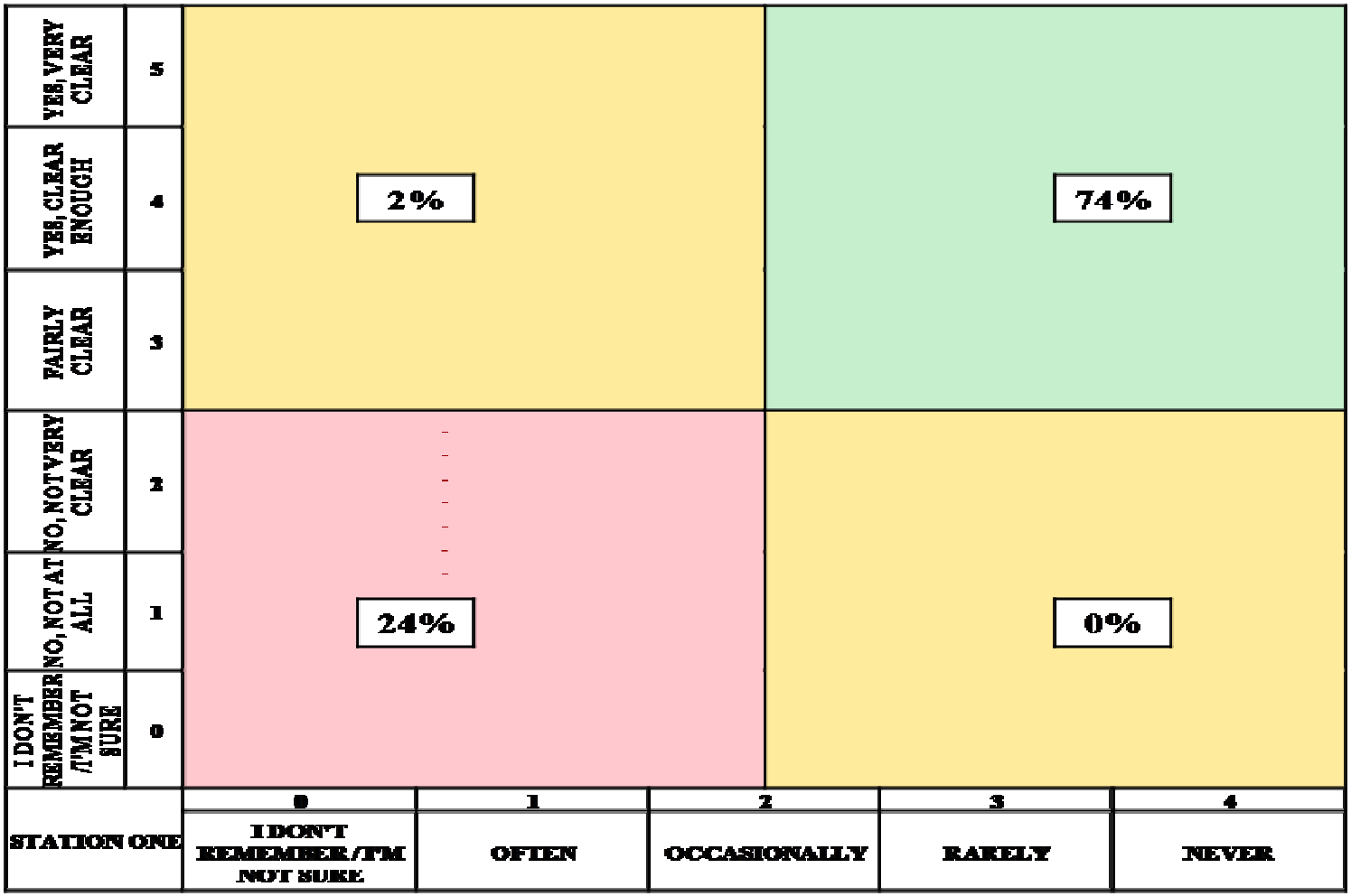

Figure 18. Questions 10 & 5 Station One

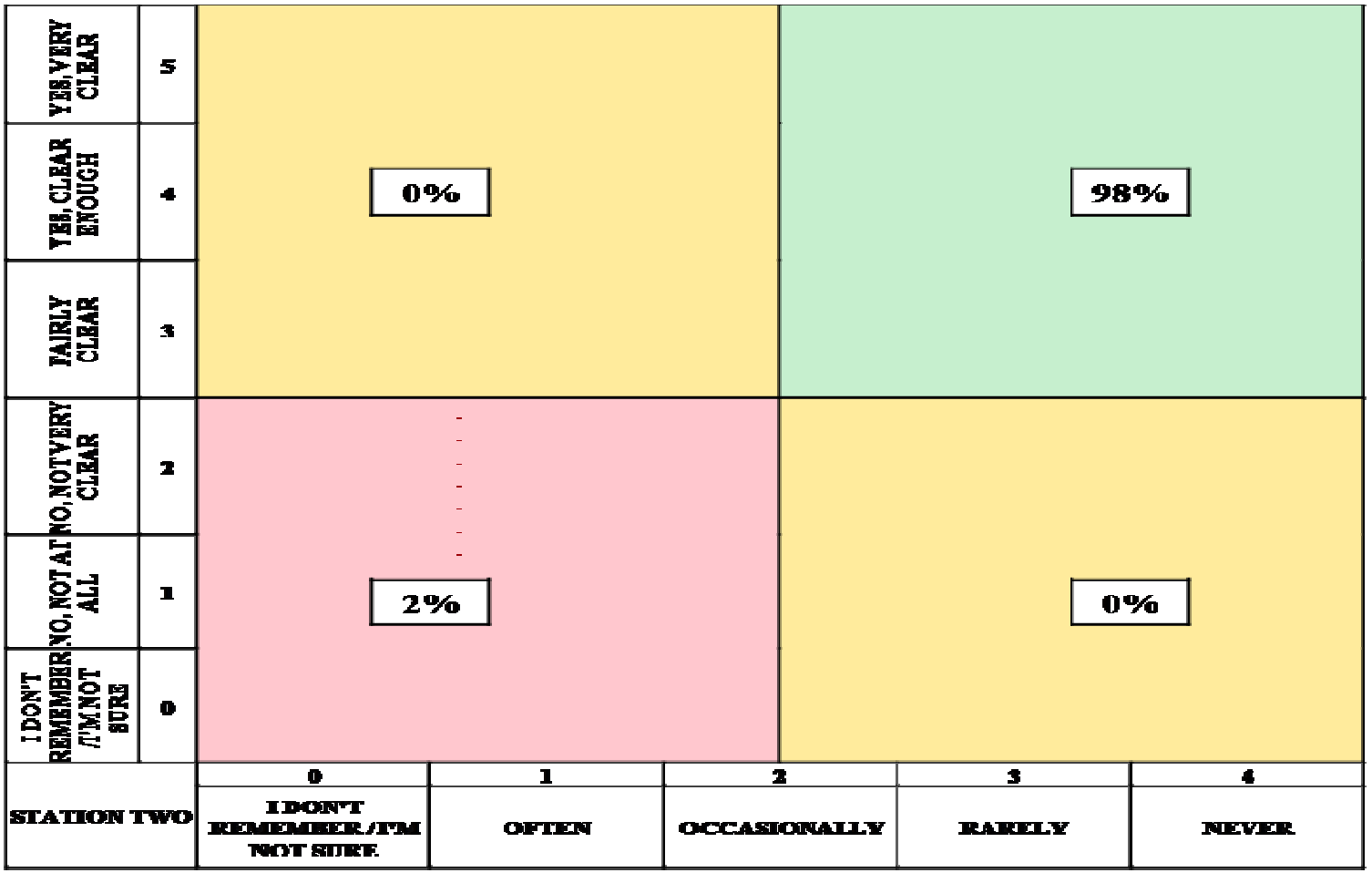

Figure 19. Questions 10 & 5 Station Two

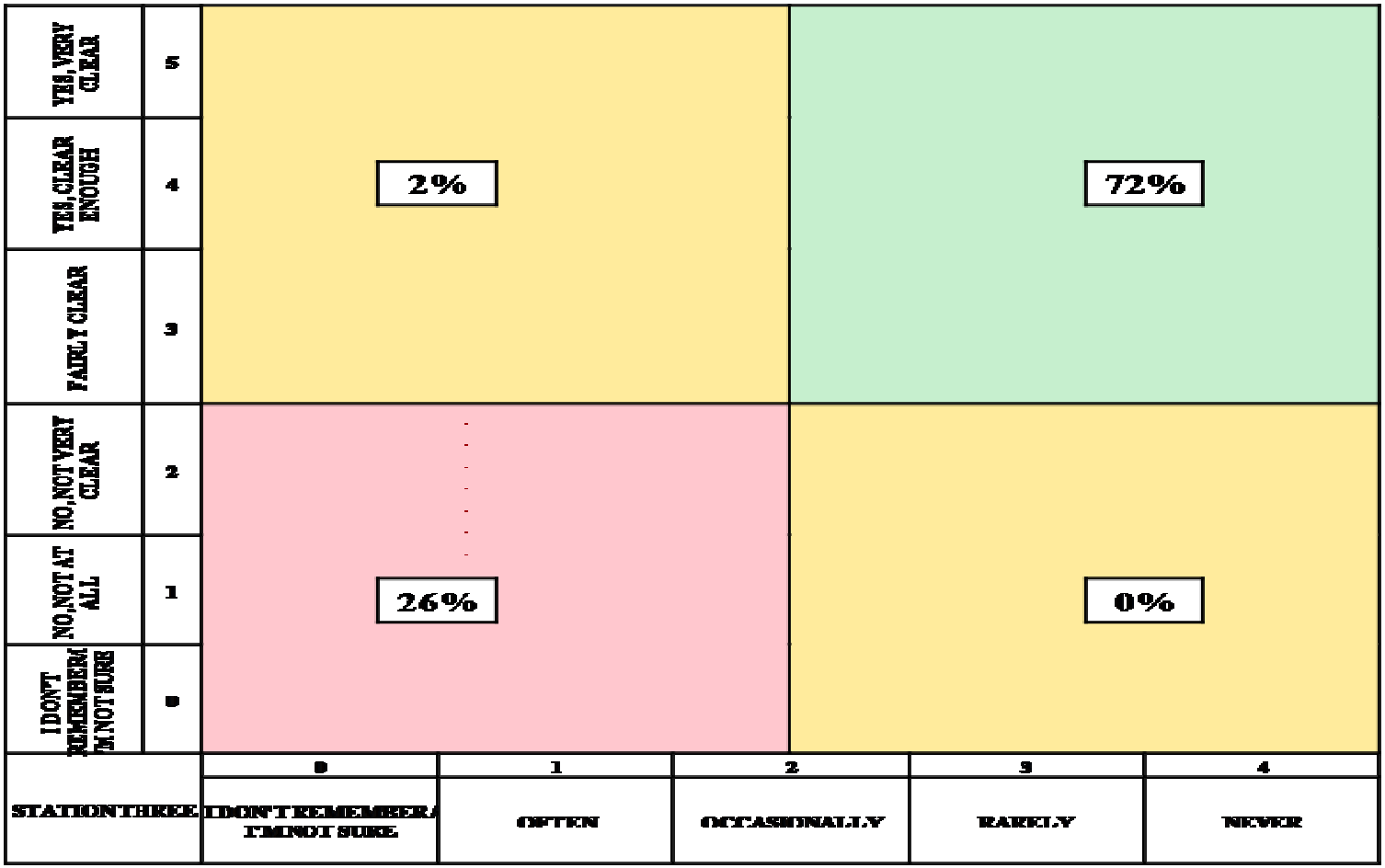

Figure 20. Questions 10 & 5 Station Three

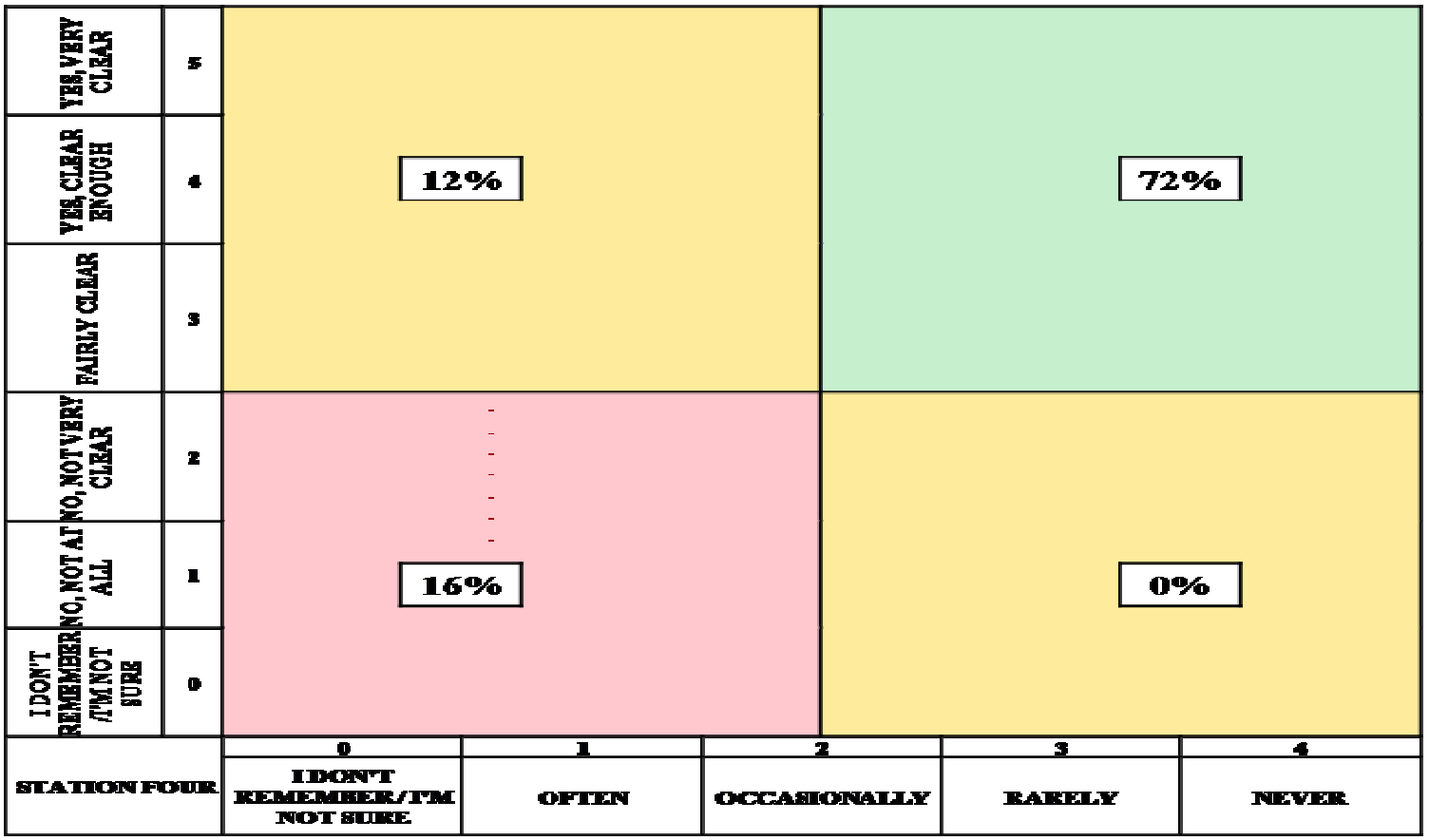

Figure 21. Questions 10 & 5 Station Four

Figures 18, 19, 20 and 21 show the percentage of responses from the 61 test subjects within each quadrant.

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APPENDIX F THESIS PROPOSAL AND IRB APPROVAL FORMS

Appendix F consists of the approved thesis proposal and institutional review board (IRB) forms.

MEMORANDUM

Date: May 29, 2007

From: LCDR COY M. ADAMS, JR.

To: Program Officer, Information Systems, and Operations, Curriculum 356

Via:
(1) Thesis Advisor, DR. CYNTHIA IRVINE
(2) Thesis Co-Advisor, DR. NELSON IRVINE
(3) Academic Associate, Information Systems and Operations Curriculum
(4) Chairman, Information Sciences Department

Subj: THESIS PROPOSAL ICO LCDR COY MONROE ADAMS, JR. 241-04-0988, USN/1110

Encl: (1) Thesis Proposal

1. Tentative Title of Proposed Thesis: VoIP Quality Measurements in A Multilevel Secure (MLS) Environment
2. General Area of Proposed Thesis Research: Multilevel Secure (MLS) Environment
3. I expect my thesis will be unclassified
4 No anticipated travel or extraordinary requirements.

Student Signature LCDR, USN 6/4/07

1 Forwarded, recommending approval: Advisor 4 June 2007 Date

2. Forwarded, recommending approval: Co-Advisor 6/4/07 Date

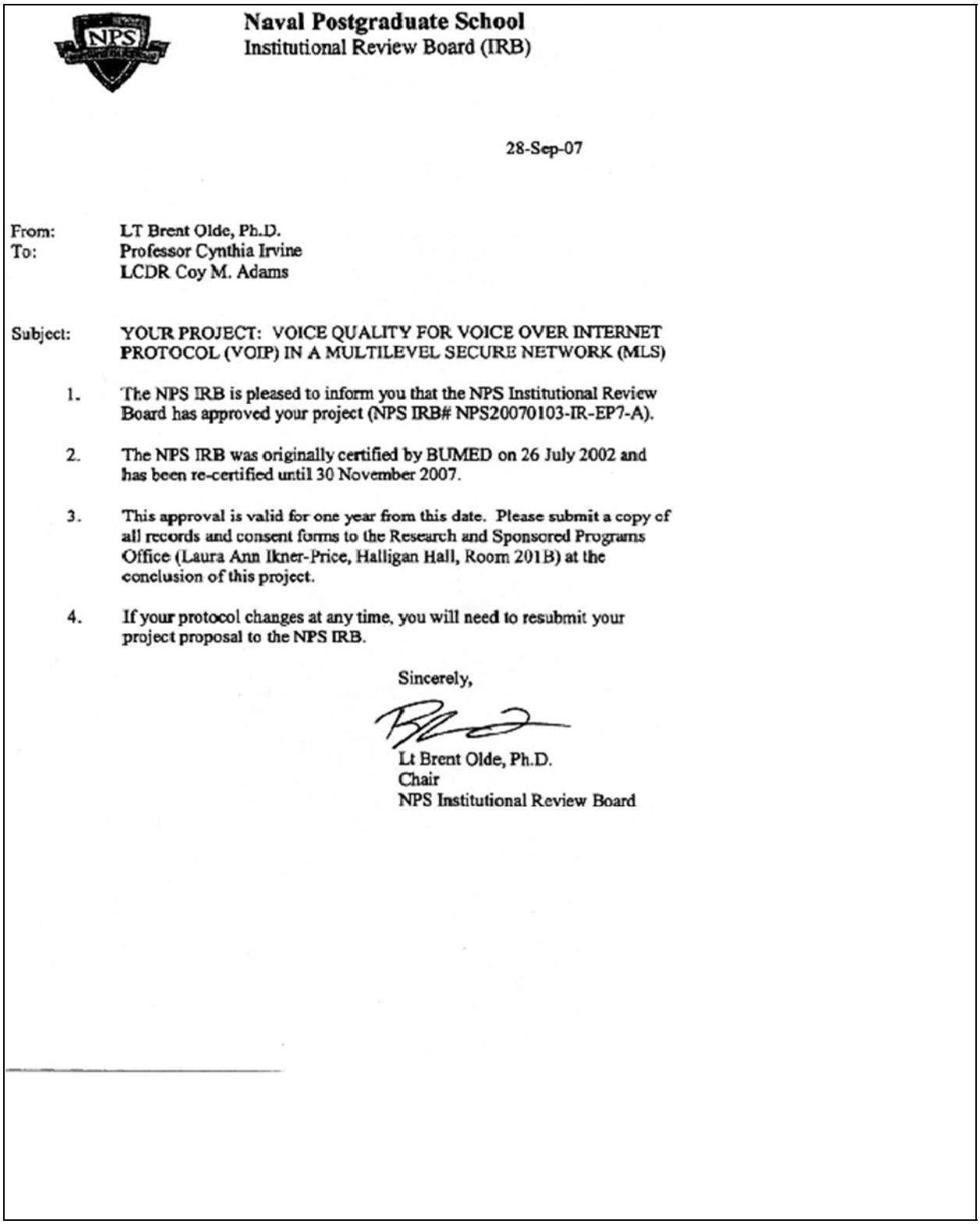
3Forwarded, recommending approval: Academic Associate, ISO 5 June 07 Date

4 Approved: Chairman, IS Department 5 JUNE 07 Date

5 Noted: Program Officer, ISO 6/4/2007 Date

1

Figure 22. Copy of Approved Thesis Proposal



Naval Postgraduate School
Institutional Review Board (IRB)

28-Sep-07

From: LT Brent Olde, Ph.D.
To: Professor Cynthia Irvine
LCDR Coy M. Adams

Subject: YOUR PROJECT: VOICE QUALITY FOR VOICE OVER INTERNET PROTOCOL (VOIP) IN A MULTILEVEL SECURE NETWORK (MLS)

1. The NPS IRB is pleased to inform you that the NPS Institutional Review Board has approved your project (NPS IRB# NPS20070103-IR-EP7-A).

2. The NPS IRB was originally certified by BUMED on 26 July 2002 and has been re-certified until 30 November 2007.

3. This approval is valid for one year from this date. Please submit a copy of all records and consent forms to the Research and Sponsored Programs Office (Laura Ann Ikner-Price, Halligan Hall, Room 201B) at the conclusion of this project.

4. If your protocol changes at any time, you will need to resubmit your project proposal to the NPS IRB.

Sincerely,

Lt Brent Olde, Ph.D.
Chair
NPS Institutional Review Board

Figure 23. Institutional Review Board (IRB) Approval

APPLICATION FOR HUMAN SUBJECTS REVIEW (HSR)	NPS IRB NUMBER *(to be assigned by RSPO)*
PRINCIPAL INVESTIGATOR(S) *(Full Name, Code, Telephone)* **Dr. Cynthia Irvine, CS Department, 831-656-2461** **Co-investigator: LCDR Coy M. Adams, 831-393-9382**	
TITLE OF EXPERIMENT **Quality of voice transmission for Voice over Internet Protocol (VoIP) in a multilevel secure (MLS) network.**	
APPROVAL REQUESTED **[X]** New [ ] Renewal [ ] Amendment	
LEVEL OF RISK [ ] Exempt **[X]** Minimal [ ] More than Minimal **All methods are non-invasive and mirror typical daily activities (e.g. phone conversation) a student might take part in with those conducting research. The student will wear a hand free PC headset with one ear piece covering the ear (nothing inserted) with a microphone arm attached, which the test subject will not use. This test is for listening observation only.**	
WORK WILL BE DONE IN (Site/Bldg/Rm) **GE-B04**	ESTIMATED NUMBER OF DAYS TO COMPLETE **45**
MAXIMUM NUMBER OF SUBJECTS **100**	ESTIMATED LENGTH OF EACH SUBJECT'S PARTICIPATION: **30-60 Minutes (approximately)**
SPECIAL POPULATIONS THAT WILL BE USED AS SUBJECTS [ ] Subordinates [ ] Minors **[X]** NPS Students [ ] Special Needs (e.g. Pregnant women) Specify safeguards to avoid undue influence and protect subject's rights: **No identifying information will be recorded or retained on the test subjects for the purpose of thesis research; names are included on the questionnaire for bookkeeping purposes ONLY. Volunteers will be provided a verbal brief on testing approach and subject rights in addition to a written consent form.**	
SCIENTIFIC MERIT REVIEW (Check all that apply) [ ] This research is part of a funded project (Job Order Number) **[X]** This research is a student thesis (Attach a copy of the approved thesis proposal) **[X]** Other (Attach a complete research proposal)	
OUTSIDE COOPERATING INVESTIGATORS AND AGENCIES **NONE APPLICABLE**	

Figure 24. Institutional Review Board (IRB) Application

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